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Monolithic zirconia: A review of the literature.

Zeynep Özkurt-Kayahan*

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

Abstract

Veneer cracking or chipping is the major complication of the zirconia based restorations. Monolithic zirconia has been introduced to overcome this problem, as well as to use in patients with limited interocclusal space. Many research articles on monolithic zirconia crowns have been published in the last years. The aim of this review article was to present data about the wear, surface roughness, fracture strength, optical properties, and marginal fit of monolithic zirconia. A PubMed search was conducted with the terms of "zirconia" with "monolithic", "full-contour", "solid", "translucent", "anatomic-contoured", "un-veneered", "non-veneered", "full-coverage". Based on the results of these studies, monolithic zirconia crowns with polished surfaces have been shown to cause the lowest wear on the antagonists compared to glazed zirconia. The fracture strength of monolithic zirconia has been found higher than veneered zirconia. Monolithic zirconia may be a promising future and long-term follow-up studies are needed to determine whether it may be an alternative to conventional veneered zirconia.

Keywords: Monolithic zirconia, Full-contour zirconia, Clinical studies, *In vitro* studies, Review.

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Introduction

Zirconia or zirconium dioxide (ZrO_2) is a highly attractive ceramic material in prosthodontics due to its excellent mechanical properties related to transformation toughening, which are the highest ever reported for any dental ceramic and enhanced natural appearance compared to metal-ceramics [1-3]. It 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) [2,3].

The high initial strength and fracture toughness of zirconia results from a physical property of partially stabilized zirconia known as "transformation toughening" [2,3]. Zirconia is a polymorphic material that has 3 crystal phases: monoclinic (m), tetragonal (t), and cubic (c). At room temperature, zirconia is in monoclinic phase and transforms into tetragonal phase at 1170°C, followed by a cubic structure at 2370°C [2]. While cooling, the metastable tetragonal zirconia is transformed into stable monoclinic zirconia. The tetragonal to monoclinic (t→m) phase transformation is associated with a large volume expansion (3-5%) that induces compressive stresses opposing crack opening and acts to increase resistance to crack propagation [3]. In vitro studies of zirconia specimens demonstrate a flexural strength of 900 to 1200 MPa and a fracture toughness of 9 to 10 MPa/m^2 [4]. It is a bioinert, not soluble metal oxide [5] that also exhibits a favorable radio-opacity and a low corrosion potential [1].

Zirconia frameworks can be produced according to two different CAD/CAM techniques. In soft machining technique, CAD/CAM systems shape pre-sintered blocks, which involves machining enlarged frameworks in a so-called green state. The enlarged pre-sintered zirconia frameworks are then sintered in a sintering furnace to their full strength that is accompanied by shrinkage of the milled framework by 25% to the desired dimensions [1]. In hard machining technique, fully sintered blocks are shaped [1]. The framework coloration is performed either adding metal oxides to the zirconia powder, or embedding the frameworks in metal salt solutions after machining [6]. Glazing is created by firing a small coating of transparent glass onto the surface or by heating the framework up to glazing temperatures for 1 to 2 minutes to get shiny glass surfaces [7].

Although zirconia has superior mechanical properties, its opaque white color and insufficient translucency require glassy porcelain veneering on the framework to achieve a natural appearance and acceptable esthetics [8]. However, cracking or chipping of the porcelain veneer has been reported to be a major complication of these restorations [9-12]. The possible causes of porcelain veneer cracking are; differences in coefficient of thermal expansion (CTE) between framework and porcelain, firing shrinkage of porcelain, porosities, poor wetting of veneering, flaws on veneering, inadequate framework design to support veneer porcelain, overloading and fatique [8].

There are several solutions to overcome the veneer cracking problem due to its multifactorial nature: alternative application of techniques for veneering such as CAD/CAM produced veneer [13], modification of the firing procedures [14], and modification of the framework design [15]. Another alternative solution was to use non-veneered zirconia restorations. The translucency of zirconia was increased and full-contoured, monolithic zirconia restorations without veneering porcelain have become increasingly popular as a result of advances in CAD/CAM technology [8,16]. The monolithic zirconia has been used in posterior region, especially for single crowns, in order to eliminate the veneer cracking [17,18]. It has been suggested for use in patients with limited interocclusal space because of its ability to resist high loads with only 0.5 mm occlusal thickness [19]. The technicians can also prepare monolithic zirconia for all-on-4 prosthesis by using CAD/CAM. Limmer et al. [20] presented 1 year results of clinical outcomes of 4 implant supported monolithic zirconia fixed dental prosthesis, and observed a few complications related to restorations. They concluded that these kinds of restorations might be a therapeutic option in the edentulous mandible.

There are 2 types monolithic zirconia materials; opaque and translucent zirconia. Opaque zirconia offers significantly greater flexural strength and indicated in the posterior regions of the mouth. Translucent zirconia has more natural esthetic properties. Lava plus high translucency zirconia (3M ESPE) has a unique shading system that gives laboratories many options for custom shading and characterization. After milling a porous green-state block, the laboratory can choose from among 18 dyeing liquids that cover the 16 Vita Classical A1-D4 shades to achieve custom coloring. The dyeing liquid is applied and then, during the sintering step, the color ions are incorporated into the zirconia. With greater strength and improved esthetics, this high translucency zirconia has the potential to be used in either the posterior or anterior regions of the mouth.

The low temperature degradation (LTD) is an aging phenomenon related to monolithic zirconia. In the presence of moisture and at low temperatures (150-400°C), slow tetragonal to monoclinic transformations occur on the surface of zirconia, then progress into the bulk of the material [21]. The growth of the transformation zone results in severe micro-cracking, grain pullout and surface roughening that leads to decrease in strength [22]. LTD was found to intensify for rougher zirconia surfaces; therefore, smooth surfaces are required to prevent LTD [23].

A definitive cementation protocol for zirconia ceramics has not been validated yet. Both the conventional and adhesive cementation techniques are feasible. For the adhesive cementation, different air-blasting protocols associated with chemical primers such as formulations containing MDP monomers or silane coupling agents are the most recommended conditioning methods for zirconia restorations, followed by dual-cured resin cements [24,25].

To date, many articles on monolithic zirconia have been published. However, there is still little general knowledge with regard to their mechanical behavior and reliability, and the factors that would contribute to their optimal application performance. Therefore, the purpose of this article is to give a succinct literature review on the material properties of monolithic zirconia, to summarize research articles conducted on this subject, and provide information on this alternative restoration type based on the results of original, full-length, scientific papers published in journals listed in PubMed.

Materials and Methods

A PubMed search was conducted up to May 2015. The terms of “zirconia” or “zirconium dioxide” or “yttria-stabilized tetragonal zirconia polycrystals (Y-TZP)” with “monolithic”, “full-contour”, “solid”, “translucent”, “anatomic-contoured”, “un-veneered”, “non-veneered”, “full-coverage” were used. The literature search covered all years and focused on publications that contained dental data regarding in vitro studies, case reports, clinical studies and reviews. The publications that used veneered zirconia, and the studies that did not use zirconia material as a superstructure were excluded. Full-text of the articles were obtained from different sources and the abstracts in English were used which were written in a different language instead of English.

Results

According to PubMed search, the total number of publications that met the inclusion criteria for this review was 49. Of these, 28 were laboratory studies, 10 were case reports, 4 were clinical studies, 4 were clinical aspects and techniques, 2 were stress analyses, and 1 was a literature review article on a special subject (wear).

Most of the studies were conducted in vitro [17,18,26-51]. Wear properties was investigated in 19 articles [17,18,26,28-34,37,41,42,44,46-50], surface roughness in 9 articles [26,28,29,31,43,45,46,48,51], fracture strength in 6 articles [35,38,40,43,49,50], optical properties and color in 4 articles [7,36,39,50], and marginal fit in 1 article [27]. There were 2 stress analyses [52,53] and 4 clinical aspects and techniques [54-57]. There was only 1 review article about the wear behavior of monolithic zirconia against enamel [58]. Other published articles were clinical studies [16,20,59,60] and case reports [61-70].

In vitro studies

Wear: Wear means “loss of material from a surface” [44]. Wear of a material is related to several factors, such as mechanical contact, surface roughness, grain size, fracture toughness, occlusal load, temperature, chemical reactions, environment and lubrication [34]. Surface conditions is one of the most crucial factor, therefore, different kinds of surface treatments should be applied on the restorative materials in order to prevent damage of natural antagonist teeth [44].

There are two common surface treatment techniques for monolithic zirconia, such as polishing (manual/machine) or glazing (glass coating/firing) to improve the esthetic appearance of the restoration and to obtain smooth surface texture. Diamond points, rubber wheels and abrasive pastes are used in polishing procedures. Glazing is performed by firing a thin coating of glass on the surface or by firing the restoration up to temperature required for glazing [7].

The wear ability of monolithic zirconia was evaluated in 19 studies. (Table 1). According to Table 1, it can be clearly observed that polished zirconia had the lowest wear on the antagonists compared to glazed zirconia. This result was attributed to the fact that glazed zirconia loses the thin glaze after a short period of clinical function, with the result of appearance of the rough and more abrasive surface of zirconia. It was also stated that glazed layer is easily removed by chair-side occlusal adjustments [47]. Only one study by Beuer et al. [50] reported higher antagonist wear with a polished zirconia than with a glazed zirconia. This difference was attributed to polishing techniques that created as smooth as or smoother than glazed surfaces in other studies. They concluded that results might be different if other polishing techniques would have been applied on zirconia surfaces.

Table 1: *In vitro studies that examined the wear properties of monolithic zirconia.*

Investigator	Tested materials	Antagonist	Zirconia system	Surface of zirconia	Results of antagonist wear	References
Sripetchdanond et al.	Monolithic zirconia	Enamel	Lava, 3M	Polished	Zirconia and resin<glass ceramic	[34]
	Glass ceramic					
	Composite resin					
Amer et al.	Monolithic zirconia	Enamel	Crystal Zirconia, Crystal	Rough	Polished zirconia showed the lowest wear	[37]
	Lithium disilicate			Polished		
	Feldspathic ceramic			Glazed		
Preis et al.	Translucent zirconia	Steatite	Experimental	Polished	Polished, ground and repolished zirconia showed the lowest wear	[41]
	Shaded zirconia			Polished and ground		
	Lithium disilicate			Polished, ground and repolished		
				Glazed		
Kim et al.	Monolithic zirconia	Enamel	Prettau, Zirkonzahn	Polished	Zirconia showed the lowest wear	[42]
	Lithium disilicate	Feldspathic ceramic	Lava, 3M		Enamel wear>Feldspathic ceramic wear	
	Feldspathic ceramic		Rainbow, Dentium			
Stawarczyk et al.	Monolithic zirconia	Enamel	Zenotec, Ivoclar	Glazed with ceramic	Polished zirconia showed the lowest wear	[44]
	Veneered zirconia			Glazed with spray		
	Metal alloy			Manually polished		
				Mechanically polished		
Luangruangrong et al.	Monolithic zirconia	Glass ceramic	Diazir, Diadem	Glazed	Glazed zirconia showed the highest wear	[46]
				Machined		
Kontos et al.	Monolithic zirconia	Steatite	Lava, 3M	Fired	Polished zirconia showed the lowest wear	[47]
				Sandblasted		
				Ground		
				Polished		
				Glazed		

Sabrah et al.	Monolithic zirconia	Synthetic hydroxyapatite	Diazir, Diadem	Machined	Glazed zirconia showed the highest wear	[48]
				Glazed		
				Ground		
				Polished		
Preis et al.	Monolithic zirconia	Steatite	Cercon, Dentsply	Sintered	Monolithic zirconia<veneered zirconia	[49]
	Veneered zirconia			Glazed	Polished, ground and repolished zirconia showed the lowest wear	
				Sandblasted and glazed		
				Polished and ground		
				Polished, ground and repolished		
Beuer et al.	Monolithic zirconia	Stainless steel	Zenotec, Ivoclar	Polished	Polished zirconia showed the highest wear***	[50]
	Veneered zirconia			Glazed		
Janyavula et al.	Monolithic zirconia	Enamel	Zenotec, Ivoclar	Polished	Polished zirconia showed the lowest wear	[26]
	Veneering ceramic			Glazed		
	Enamel			Polished and glazed		
Mörmann et al.	Monolithic zirconia	Enamel	InCoris TZI, Sirona	Polished	Monolithic zirconia showed the lowest wear	[28]
	Lithium disilicate					
	Leucite glass					
	Feldspathic ceramic					
	Hybrid ceramic					
	Composite resin					
	PMMA					
	Enamel					
Mitov et al.	Monolithic zirconia	Enamel	Everest ZH, Kavo	Polished	Polished zirconia showed the lowest wear	[29]
	Leucite glass			Ground		
				Glazed		
Jung et al.	Monolithic zirconia	Enamel	Prettau, Zirkonzahn	Polished	Polished zirconia showed the lowest wear	[30]
	Feldspathic ceramic			Glazed		
Preis et al.	Monolithic zirconia	Enamel	Cercon, Dentsply	Polished	Polished, ground and repolished zirconia showed no wear	[31]
	Feldspathic ceramic	Steatite	Lava, 3M	Polished and ground		
				Polished, ground and repolished		

Preis et al.	Monolithic zirconia	Enamel	Zenotec, Ivoclar	Glazed	Monolithic zirconia<other groups	[17]
	Veneered zirconia	Steatite				
	Feldspathic ceramic					
	Enamel					
Rosentritt et al.	Monolithic zirconia	Enamel	Prettau, Zirkonzahn	Glazed	Monolithic zirconia<other groups	[18]
	Veneered zirconia	Steatite				
	Feldspathic ceramic					
	Lithium disilicate					
	Glass infiltrated ceramics					
	Enamel					
Albashaireh et al.	Monolithic zirconia	Lithium disilicate	Zenotec, Ivoclar	Polished	Monolithic zirconia<other groups	[32]
		Leucite glass				
		Fluorapatite glass				
		Nanofluorapatite glass				
Park et al.	Monolithic zirconia	Enamel	Prettau, Zirkonzahn	Polished	Monolithic zirconia<feldspathic ceramic	[33]
	Feldspathic ceramic		Zenotec, Ivoclar ZirBlank, BruxZir	Glazed	Glazed zirconia>polished zirconia	

Surface roughness: Preparing a smooth surface for ceramic restorations is considered as an important step because increased surface roughness associated with improper surface treatment can increase wear rate of the opposing teeth and can compromise the clinical performance of the restorations [71,72].

The surface roughness of monolithic zirconia was evaluated in 9 studies. Ghazal et al. [51] evaluated the effect of surface roughness of zirconia on the wear of antagonist enamel and composite resin, and found that an increase in the surface roughness significantly increased the wear of enamel and composite resin. They also reported that the maximum surface roughness of zirconia should not be greater than 0.75 µm. Alghazzawi et al. [43] found that surface roughness of polished monolithic zirconia was significantly increased with aging procedures, because the volume expansion associated with the phase transformation (tetragonal to monoclinic) during LTD leaded to grain pushout that imparted the surface roughening. Mörmann et al. [28] stated that the gloss of zirconia was slightly increased and the roughness was decreased after toothbrushing. Preis et al. [31] reported that smoother surfaces were obtained with the polished zirconia compared to ground zirconia. Hmaidouch et al. [45] investigated the effect of controlled intraoral grinding and polishing on the roughness of monolitic zirconia and compered it to veneered zirconia in their study. They reported that fewer defects and lower roughness values were obtained in monolithic zirconia compared to veneered zirconia. In addition, they found that lower roughness values were achieved after polishing compared to glazing procedure. It was showed in another study that [46], machined zirconia had higher surface roughness than glazed zirconia. Similarly, the glazed surface was found smoother than polished and ground surface [48].

However, controversial results have been obtained in other studies [26,29]. Janyavula et al. [26] found that the polished surfaces of monolithic zirconia were smoother than glazed surfaces. It was stated by Mitov et al. [29] that polished zirconia showed a lower surface roughness than glazed and ground zirconia. These differences may be due to the different polishing (machine or manual) and glazing (glass coating, firing) techniques, or different study protocols. It was known that machine polishing results in a significantly higher surface gloss of ceramics than manual polishing with tools for intraoral polishing [73].

Fracture strength: Fracture strength was investigated in 6 articles. In a study by Zesewitz et al. [35], zirconia showed the highest strength when luted with adhesive resin or glass-ionomer cements, compared to lithium disilicate and feldspathic ceramics. Similar results were obtained with Zhang et al. study [40]. In another study by Sun et al. [38], monolithic zirconia crown with a thickness of 1 mm was found equal to metal-ceramic crowns. It was also reported that strength of monolithic zirconia was higher than veneered zirconia, lithium disilicate and metal-ceramics. These results are in agreement with the study by Beuer et al. [50] that has reported monolithic zirconia had higher strength than veneered zirconia. On the contrary, the strength of monolithic and veneered zirconia was found similar in Preis et al. study [49]. Alghazzawi et al. [43] found that the strength values were not altered significantly between aged and non-aged monolithic zirconia crowns. As a result of these studies, it can suggest that monolithic zirconia that has a promising future may be an alternative to traditional veneered zirconia.

Optical properties: The creation of acceptable esthetic result with monolithic zirconia restorations is challenging because they are mono-layered restorations. Application of coloring liquids, surface characterization, glazing and polishing of zirconia are the procedures to look like natural teeth [36]. Significantly improved color adaptation to adjacent teeth is accomplished with coloring of the monolithic zirconia structures, followed by individual color characterizations achieved by surface painting. The coloring liquids with different color intensities are applied with a paintbrush prior to sintering [54].

The translucency of the monolithic zirconia restoration is also essential for optimized esthetic outcome. However, an increase in crystalline content and framework thickness in order to achieve high strength would generally result in lower translucency. Zirconia has higher contrast ratio compared to glass ceramics, and can be clinically applied with a minimum thickness of 0.4 mm [74].

There are few studies in the literature reporting optical properties and color of monolithic zirconia. In a study by Kim et al. [36] the effect of number of coloring liquid applications on color, translucency and opalescence of monolithic zirconia was investigated. The increased number of coloring liquid applications reduced the lightness and opalescence. Sari et al. [39] reported that transmission of Er:YAG laser through monolithic zirconia was lower than leucide and lithium-disilicate reinforced glass ceramics. In another study by Kim et al. [7] it was found that polishing and glazing procedures decreased lightness, glazing increased yellowness, and increased number of coloring liquid applications made zirconia darker and more yellowish. When compared polished and glazed monolithic zirconia with veneered zirconia, it was stated that polished zirconia showed higher light translucency [50].

Marginal fit: Karl et al. [27] investigated the quality of fit of zirconia crowns and they found that monolithic zirconia showed greater passivity of fit than veneered zirconia. They showed that ceramic veneering of zirconia frameworks resulted in an increase in strain development. Monolithic contour restorations exhibited less strain.

Stress analyses studies

There are 2 studies in the literature regarding stress analyses of monolithic zirconia [52,53]. In the first study [52], the fracture load of zirconia was found 1.8 times greater than lithium disilicate when supported by dentin and 1.3 times greater than lithium disilicate when supported by enamel. In the second study [53] monolithic crown systems (zirconia, alumina, metal, all porcelain) were compared with the veneered crowns (zirconia, alumina, metal) in terms of compressive stress. For monolithic systems, the all porcelain showed the highest concentration of compressive stresses followed by zirconia, alumina and metal.

Clinical studies

Four articles were included in the clinical follow-up studies associated with monolithic zirconia [16,20,59,60]. Batson et al. [59] fabricated a total of 32 monolithic zirconia, metal ceramic and lithium disilicate posterior single crown restorations in 22 patients and evaluated them at the 6-month visit. They observed that monolithic zirconia crowns were superior in occlusion (only 20% needed adjustment) and marginal adaptation (least amount of horizontal marginal discrepancy). In another study, clinical complications and survival rates of implant supported monolithic zirconia fixed dental prosthesis in 17 edentulous patients at the 12 month visit [20]. Prosthesis survival was 88%. One of the prosthesis was fractured and the other prosthesis was removed due to the implant failure. In a clinical study by Wang et al. [60], esthetic, wear and fracture were evaluated in 35 monolithic zirconia crowns in 30 patients after 24-month visit. No fracture was found, the esthetic was satisfactory but antagonist enamel wear was observed. Stober et al. [16] evaluated the enamel wear caused by 20 monolithic zirconia crowns in 20 patients after 6 months of clinical use, and found that zirconia crowns caused greater wear of opposed enamel compared to natural teeth. Although the enamel wear was greater than natural teeth, previous studies [75,76] claimed that the wear is lower than or comparable with other ceramic restorations such as metal-ceramics, alumina and glass-ceramics. Therefore, further clinical evaluations of wear with various ceramic crown systems and over a longer time period should be conducted.

Discussion

Nowadays, monolithic zirconia has become popular because of their high flexural strength, natural tooth color, less wear on the antagonists, and minimum tooth preparation [8,16]. For the patients with compromised occlusion or parafunction, monolithic zirconia crowns may be fabricated with as little as 0.5 mm of occlusal reduction [19]. It is possible to produce CAD/CAM-milled monolithic zirconia restorations with the new digital impression technology such as CEREC (Sirona Dental Systems) or Lava Chairside Oral Scanner (3M ESPE) [8]. The color of the restoration is homogeneous and there is no need for concern about opaque show-through during adjustment of the occlusion. It is also easy to shape and polish the material using porcelain-polishing materials [36,54].

Zirconia has been considered an opaque material compared to other all ceramics, but more esthetic alternative to porcelain fused to metals (PFMs) or cast gold restorations, in the areas with limited occlusal spaces [74]. The translucency of monolithic zirconia should be improved to make it a restorative option in the anterior region as well. The cementation is either adhesive or conventional [24,25].

This article reviewed the outcomes of laboratory and clinical studies of monolithic zirconia. The number of the articles was limited because this material has been used in a short time compared to other materials used in prosthodontics restorations. Most of the clinical studies had short follow-up periods ranging from 6 to 24 months. However, the solutions of the clinical complications of this material were not be pointed. Therefore, clinicians should be careful about the indications and limitations when making decisions regarding monolithic zirconia. According to results of the in vitro studies, it can be clearly seen that polished monolithic zirconia surfaces caused the lowest wear on the opposing teeth compared to glazed zirconia surfaces [58]. The wear is affected by the surface roughness, and machine polishing technique seems to be more successful in this manner, because the glaze layer is removed during the wear process. When considered the fracture strength of the material, it was found better than veneered zirconia [38,50].

Conclusions

This paper reviewed the available literature on monolithic zirconia restorations. Monolithic zirconia is emerging as a promising option. Many in vitro studies on monolithic zirconia have been published to date; however, clinical long-term evaluation is crucial and mandatory to a more thorough understanding of the mechanical behavior and reliability of these restorations. LTD in non-veneered zirconia restorations may cause severe clinical problems after several years of clinical service. As an alternative monolithic ceramic material to zirconia, lithium disilicate may be used in the clinical practice, which longer-term clinical data have been already published [77-80]. The authors believe that before monolithic zirconia crowns are used widely and prevalently in dental practice, studies of longer duration are necessary to validate this material. Despite the reported advantages and short-term favorable clinical reports, long-term follow-up studies of at least 10 years should be conducted. These studies will provide the much-needed data pertaining to the efficacy of zirconia material for full-contour restorations.

Conflict of Interest

The authors deny any conflict of interest.

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, Torre JP, Peille CN. Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989; 23: 45-61.
5. Akagawa Y, Ichikawa Y, Nikai H, Tsuru H. Interface histology of unloaded and early loaded partially stabilized zirconia endosseous implant in initial bone healing. J Prosthet Dent 1993; 69: 599-604.
6. Zarone F, Russo S, Sorrentino R. From porcelain-fused-to-metal to zirconia: clinical and experimental considerations. Dent Mater 2011; 27: 83-96.
7. Kim HK, Kim SH, Lee JB, Han JS, Yeo IS. Effect of polishing and glazing on the color and spectral distribution of monolithic zirconia. J Adv Prosthodont 2013; 5: 296-304.
8. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res 2013; 57: 236-261.
9. Sailer I, Feher A, Filser F, Gauckler LJ, Lüthy H, Hämmerle CH. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 2007; 20: 383-388.
10. Sailer I, Feher A, Filser F, Lüthy H, Gauckler LJ, Schärer P, Franz Hämmerle CH. Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 2006; 37: 685-693.
11. 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.
12. Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S, Mercante DE. 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.
13. Schmitter M, Mueller D, Rues S. In vitro chipping behaviour of all-ceramic crowns with a zirconia framework and feldspathic veneering: comparison of CAD/CAM-produced veneer with manually layered veneer. J Oral Rehabil 2013; 40: 519-525.
14. Rues S, Kröger E, Müller D, Schmitter M. Effect of firing protocols on cohesive failure of all-ceramic crowns. J Dent 2010; 38: 987-994.
15. Rosentritt M, Steiger D, Behr M, Handel G, Kolbeck C. Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns. J Dent 2009; 37: 978-983.
16. Stober T, Bermejo JL, Rammelsberg P, Schmitter M. Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use. J Oral Rehabil 2014; 41: 314-322.
17. Preis V, Behr M, Kolbeck C, Hahnel S, Handel G, Rosentritt M. Wear performance of substructure ceramics and veneering porcelains. Dent Mater 2011; 27: 796-804.

18. Rosentritt M, Preis V, Behr M, Hahnel S, Handel G, Kolbeck C. Two-body wear of dental porcelain and substructure oxide ceramics. Clin Oral Investig 2012; 16: 935-943.
19. Jang GW, Kim HS, Choe HC, Son MK. Fracture strength and mechanism of dental ceramic crown with zirconia thickness. Procedia Eng 2011; 10: 1556-1560.
20. Limmer B, Sanders AE, Reside G, Cooper LF. Complications and patient-centered outcomes with an implant-supported monolithic zirconia fixed dental prosthesis: 1 year results. J Prosthodont 2014; 23: 267-275.
21. Kelly JR, Denry I. Stabilized zirconia as a structural ceramic: an overview. Dent Mater 2008; 24: 289-298.
22. Guess PC, Schultheis S, Bonfante EA, Coelho PG, Ferencz JL, Silva NR. All-ceramic systems: laboratory and clinical performance. Dent Clin North Am 2011; 55: 333-352.
23. Pereira G, Amaral M, Cesar PF, Bottino MC, Kleverlaan CJ, Valandro LF. Effect of low-temperature aging on the mechanical behavior of ground Y-TZP. J Mech Behav Biomed Mater 2015; 45: 183-192.
24. Re D, Augusti D, Augusti G, Giovannetti A. Early bond strength to low-pressure sandblasted zirconia: evaluation of a self-adhesive cement. Eur J Esthet Dent 2012; 7: 164-175.
25. Zandparsa R, Talua NA, Finkelman MD, Schaus SE. An in vitro comparison of shear bond strength of zirconia to enamel using different surface treatments. J Prosthodont 2014; 23: 117-123.
26. Janyavula S, Lawson N, Cakir D, Beck P, Ramp LC, Burgess JO. The wear of polished and glazed zirconia against enamel. J Prosthet Dent 2013; 109: 22-29.
27. Karl M, Graef F, Wichmann M, Krafft T. Passivity of fit of CAD/CAM and copy-milled frameworks, veneered frameworks, and anatomically contoured, zirconia ceramic, implant-supported fixed prostheses. J Prosthet Dent 2012; 107: 232-238.
28. Mörmann WH, Stawarczyk B, Ender A, Sener B, Attin T, Mehl A. Wear characteristics of current aesthetic dental restorative CAD/CAM materials: two-body wear, gloss retention, roughness and Martens hardness. J Mech Behav Biomed Mater 2013; 20: 113-125.
29. Mitov G, Heintze SD, Walz S, Woll K, Muecklich F, Pospiech P. Wear behavior of dental Y-TZP ceramic against natural enamel after different finishing procedures. Dent Mater 2012; 28 :909-918.
30. Jung YS, Lee JW, Choi YJ, Ahn JS, Shin SW, Huh JB. A study on the in-vitro wear of the natural tooth structure by opposing zirconia or dental porcelain. J Adv Prosthodont 2010; 2: 111-115.
31. Preis V, Behr M, Handel G, Schneider-Feyrer S, Hahnel S, Rosentritt M. Wear performance of dental ceramics after grinding and polishing treatments. J Mech Behav Biomed Mater 2012; 10: 13-22.
32. Albashaireh ZS, Ghazal M, Kern M. Two-body wear of different ceramic materials opposed to zirconia ceramic. J Prosthet Dent 2010; 104: 105-113.
33. Park JH, Park S, Lee K, Yun KD, Lim HP. Antagonist wear of three CAD/CAM anatomic contour zirconia ceramics. J Prosthet Dent 2014; 111: 20-29.
34. Sripetchdanond J, Leevailoj C. Wear of human enamel opposing monolithic zirconia, glass ceramic, and composite resin: An in vitro study. J Prosthet Dent 2014; 112: 1141-1150.
35. Zesewitz TF, Knauber AW, Northdurft FP. Fracture resistance of a selection of full-contour all-ceramic crowns: an in vitro study. Int J Prosthodont 2014; 27: 264-266.
36. Kim HK, Kim SH. Effect of the number of coloring liquid applications on the optical properties of monolithic zirconia. Dent Mater 2014; 30: e229-237.
37. Amer R, Kürklü D, Kateeb E, Seghi RR. Three-body wear potential of dental yttrium-stabilized zirconia ceramic after grinding, polishing, and glazing treatments. J Prosthet Dent 2014; 112: 1151-1155.
38. Sun T, Zhou S, Lai R, Liu R, Ma S, Zhou Z, Longquan S. Load-bearing capacity and the recommended thickness of dental monolithic zirconia single crowns. J Mech Behav Biomed Mater 2014; 35: 93-101.
39. Sari T, Tuncel I, Usumez A, Gutknecht N. Transmission of Er:YAG laser through different dental ceramics. Photomed Laser Surg 2014; 32: 37-41.
40. Zhang Y, Lee JJ, Srikanth R, Lawn BR. Edge chipping and flexural resistance of monolithic ceramics. Dent Mater 2013; 29: 1201-1208.
41. Preis V, Weiser F, Handel G, Rosentritt M. Wear performance of monolithic dental ceramics with different surface treatments. Quintessence Int 2013; 44: 393-405.
42. Kim MJ, Oh SH, Kim JH, Ju SW, Seo DG, Jun SH, Ahn JS, Ryu JJ. Wear evaluation of the human enamel opposing different Y-TZP dental ceramics and other porcelains. J Dent 2012; 40: 979-988.
43. Alghazzawi TF, Lemons J, Liu PR, Essig ME, Bartolucci AA, Janowski GM. Influence of low-temperature environmental exposure on the mechanical properties and structural stability of dental zirconia. J Prosthodont 2012; 21: 363-369.
44. Stawarczyk B, Özcan M, Schmutz F, Trottmann A, Roos M, Hämmerle CH. Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists. Acta Odontol Scand 2013; 71: 102-112.
45. Hmaidouch R, Müller WD, Lauer HC, Weigl P. Surface roughness of zirconia for full-contour crowns after clinically simulated grinding and polishing. Int J Oral Sci 2014; 6: 241-246.
46. Luangruangrong P, Cook NB, Sabrah AH, Hara AT, Bottino MC. Influence of full-contour zirconia surface roughness on wear of glass-ceramics. J Prosthodont 2014; 23: 198-205.
47. Kontos L, Schille C, Schweizer E, Geis-Gerstorfer J. Influence of surface treatment on the wear of solid zirconia. Acta Odontol Scand 2013; 71: 482-487.
48. Sabrah AH, Cook NB, Luangruangrong P, Hara AT, Bottino MC. Full-contour Y-TZP ceramic surface roughness effect

on synthetic hydroxyapatite wear. Dent Mater 2013; 29: 666-673.

49. Preis V, Behr M, Hahnel S, Handel G, Rosentritt M. In vitro failure and fracture resistance of veneered and full-contour zirconia restorations. J Dent 2012; 40: 921-928.
50. Beuer F, Stimmelmayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater 2012; 28: 449-456.
51. Ghazal M, Kern M. The influence of antagonistic surface roughness on the wear of human enamel and nanofilled composite resin artificial teeth. J Prosthet Dent 2009; 101: 342-349.
52. Ma L, Guess PC, Zhang Y. Load-bearing properties of minimal-invasive monolithic lithium disilicate and zirconia occlusal onlays: finite element and theoretical analyses. Dent Mater 2013; 29: 742-751.
53. Bonfante EA, Rafferty BT, Silva NR, Hanan JC, Rekow ED, Thompson VP, et al. Residual thermal stress simulation in three-dimensional molar crown systems: a finite element analysis. J Prosthodont 2012; 21: 529-534.
54. Rinke S, Fischer C. Range of indications for translucent zirconia modifications: clinical and technical aspects. Quintessence Int 2013; 44: 557-566.
55. Griffin JD Jr. Tooth in a bag: same-day monolithic zirconia crown. Dent Today 2013; 32: 126-131.
56. Griffin JD Jr. Combining monolithic zirconia crowns, digital impressioning, and regenerative cement for a predictable restorative alternative to PFM. Compend Contin Educ Dent 2013; 34: 212-222.
57. Christensen R. Focus on: Monolithic crowns. Dent Today 2013; 32: 22.
58. Passos SP, Torrealba Y, Major P, Linke B, Flores-Mir C, Nychka JA. In Vitro Wear Behavior of Zirconia Opposing Enamel: A Systematic Review. J Prosthodont 2014; 23: 593-601.
59. Batson ER, Cooper LF, Duqum I, Mendonça G. Clinical outcomes of three different crown systems with CAD/CAM technology. J Prosthet Dent 2014; 112: 770-777.
60. Wang YG, Xing YX, Sun YC, Zhao YJ, Lü PJ, Wang Y. Preliminary evaluation of clinical effect of computer aided design and computer aided manufacture zirconia crown. Zhonghua Kou Qiang Yi Xue Za Zhi 2013; 48: 355-358.
61. Augusti D, Augusti G, Borgonovo A, Amato M, Re D. Inlay-retained fixed dental prosthesis: a clinical option using monolithic zirconia. Case Rep Dent 2014; 2014: 629786.
62. Mehra M, Vahidi F. Complete mouth implant rehabilitation with a zirconia ceramic system: a clinical report. J Prosthet Dent 2014; 112: 1-4.
63. Thalji GN, Cooper LF. Implant-supported fixed dental rehabilitation with monolithic zirconia: a clinical case report. J Esthet Restor Dent 2014; 26: 88-96.
64. Cheng CW, Chien CH, Chen CJ, Papaspyridakos P. Complete-mouth implant rehabilitation with modified monolithic zirconia implant-supported fixed dental prostheses and an immediate-loading protocol: a clinical report. J Prosthet Dent 2013; 109: 347-352.
65. Sadid-Zadeh R, Liu PR, Aponte-Wesson R, O'Neal SJ. Maxillary cement retained implant supported monolithic zirconia prosthesis in a full mouth rehabilitation: a clinical report. J Adv Prosthodont 2013; 5: 209-217.
66. Rojas-Vizcaya F. Full zirconia fixed detachable implant-retained restorations manufactured from monolithic zirconia: clinical report after two years in service. J Prosthodont 2011; 20: 570-576.
67. Long HA. A predictable approach to an all-ceramic full-arch restoration. Compend Contin Educ Dent 2013;34:274-81.
68. Holt LR, Boksman L. Monolithic zirconia: minimizing adjustments. Dent Today 2012; 31: 78, 80-81.
69. Ramsey C. Predictable cementation for monolithic zirconia crowns. Dent Today 2014; 33: 114, 116.
70. Zimmermann R, Seitz S, Magness B, Wieck B. Using CAD/CAM technology to create a 10-unit zirconia fixed partial denture--a UTHSCSA dental school case report. Tex Dent J 2013; 130: 1039-1044.
71. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater 1997; 13: 258-269.
72. Magne P, Oh WS, Pintado MR, DeLong R. Wear of enamel and veneering ceramics after laboratory and chairside finishing procedures. J Prosthet Dent 1999; 82: 669-679.
73. Heintze SD, Forjanic M, Rousson V. Surface roughness and gloss of dental materials as a function of force and polishing time in vitro. Dent Mater 2006; 22: 146-165.
74. Stawarczyk B, Emslander A, Roos M, Sener B, Noack F, Keul C. Zirconia ceramics, their contrast ratio and grain size depending on sintering parameters. Dent Mater J 2014; 33: 591-598.
75. Etman MK, Woolford M, Dunne S. Quantitative measurement of tooth and ceramic wear: in vivo study. Int J Prosthodont 2008; 21: 245-252.
76. Esquivel-Upshaw JF, Rose WF Jr, Barrett AA, Oliveira ER, Yang MC, Clark AE, et al. Three years in vivo wear: core-ceramic, veneers, and enamel antagonists. Dent Mater 2012; 28: 615-621.
77. Cortellini D, Canale A. Bonding lithium disilicate ceramic to feather-edge tooth preparations: a minimally invasive treatment concept. J Adhes Dent 2012; 14: 7-10.
78. Kern M, Sasse M, Wolfart S. Ten-year outcome of three-unit fixed dental prostheses made from monolithic lithium disilicate ceramic. J Am Dent Assoc 2012; 143: 234-240.
79. Reich S, Endres L, Weber C, Wiedhahn K, Neumann P, Schneider O, Rafai N, Wolfart S. Three-unit CAD/CAM-generated lithium disilicate FDPs after a mean observation time of 46 months. Clin Oral Investig 2014; 18: 2171-2218.
80. Guess PC, Selz CF, Steinhart YN, Stampf S, Strub JR. Prospective clinical split-mouth study of pressed and CAD/CAM all-ceramic partial-coverage restorations: 7-year results. Int J Prosthodont 2013; 26: 21-25.

*Correspondence to:

Zeynep Özkurt-Kayahan

Faculty of Dentistry

Department of Prosthodontics, Bağdat cad. No: 238

Yeditepe University

34728, Goztepe, Istanbul

Turkey