Chapter

The Application of Zirconia in Tooth Defects

Feng Luo, Hongyan Luo, Ruyi Li, Changxing Qu, Guang Hong and Qianbing Wan

Abstract

Dental caries is among the most prevalent chronic diseases of childhood, affecting larger part of children and adults. Non-treated enamel caries can lead to destruction and then spreads into the underlying softer and sensitive dentine layer. Dental restorative materials are applied to treat and reconstruct damaged teeth clinically and recover their functions. Currently, there are various dental restorative materials available, and many appropriate materials are used to restore dental carious teeth. The applicability of biomimetic principles can elicit innovations in restorative dentistry for tooth conservation and preservation. There are three types of materials commonly used in dental restorations: resin, alloys, and ceramic. During the past decade, zirconia-based ceramics have been successfully introduced into the clinic due to acceptable biocompatibility, lower price compared with gold restorations, and better appearance than traditional metal-ceramic restorations. Recently, zirconia restoration is an acceptable treatment option in restorative dentistry and a developing trend in esthetic dentistry.

Keywords: dental caries, dental restorative materials, biomimetic principles, resin, zirconia

1. Introduction

Human teeth have a complex structure with an inner core of highly vascular, soft, and delicate pulp surrounded by the highly mineralized enamel and dentin tissues (**Figure 1**) [1]. The structure of teeth can be altered by diet, age, or diseases such as caries and sclerosis. Currently, dental caries is among the most prevalent chronic diseases of childhood, affecting 60–90% of school-aged children and the larger part of adults [2]. Non-treated enamel caries can lead to destruction and then spreads into the underlying softer and sensitive dentine layer. Dental caries could attack the cement of the root and cause gum recession and periodontitis [3]. Dental enamel is composed of long and parallel mineralized crystals containing 90–92% hydroxyapatite, 1–2% organic matrix proteins, and 4–12% water [4]. In addition, the thickness of enamel is different in different anatomical parts of different teeth. For instance, the enamel thickness at the cementum-enamel junction (CEJ) is thinner than the occlusal/incisal surface. Further, the average enamel thickness of incisal edge, premolar cusp, and molar cusp are 2 mm, 2.3–2.5 mm, and 2.5–3 mm, respectively [5]. Dentin is composed of inorganic (50% by volume) and organic material (30% by volume; 90% of which is type 1 collagen and 10%

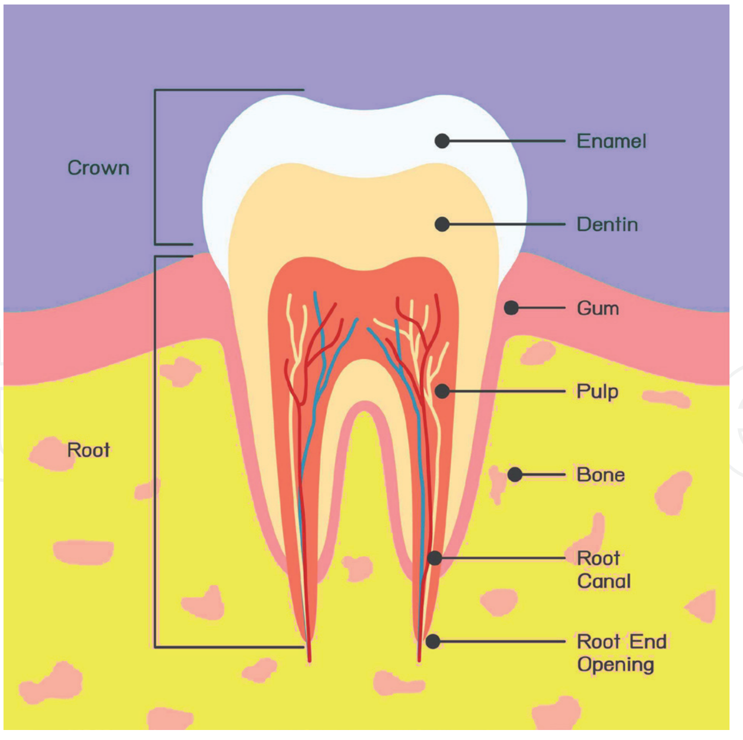

Figure 1.
Structure of human tooth. Human teeth have a complex structure with an inner core of highly vascular, soft, and delicate pulp surrounded by the highly mineralized enamel and dentin tissues.

non-collagenous proteins) [6]. Dentin covers most of the tooth structure, and it is externally covered by enamel and cementum.

Unfortunately, dental caries is non-avoidable disease. The tooth's hard tissue, included the enamel and dentin, is typically damaged by dental caries. The shape and function of the teeth are also impaired. In spite of much effort in oral health promotion and preventive methods, dental restorations are still needed. Natural teeth are always considered to be a reference while employing biomimetic approaches to restore diseased or fractured dental tissues [7]. The main goal of restorative dentistry is to create a restoration that can mineralize initial enamel and dentinal lesions in native form. Besides, restorative dentistry aims to develop material that can mimic natural teeth' structural, functional, and biological properties.

Dental restorative materials are applied to treat and reconstruct damaged teeth clinically and recover their functions [8]. Currently, there are various dental restorative materials available, and many appropriate materials are used to restore dental carious teeth. At a macrostructural level, various biomimetic restorative materials can be applied to achieve the teeth' biomechanical, structural, and aesthetic integrity. For this purpose, materials scientists take natural teeth as a reference during the development of dental restorative materials. The widespread application of bionic principles in the field of dentistry can also promote the innovation of restorative dentistry, especially in the field of protection and preservation of teeth. For example, when restoring damaged parts of teeth, dentists should pay more attention to factors, such as color tone, internal coronal anatomy, mechanics, and tooth position in the dental arch [9]. There are three types of materials commonly used in dental restorations: resin, alloys, and ceramic [10]. In dental clinical, resin dental composites and glass-ionomer cements are commonly used to restore features depending on the extent of damage and aesthetic requirement. While alloy and ceramic materials are mainly used for fixed restorations (e.g., fixed dentures), removable restorations mainly use nano-resins and alloys. Recently, the most prevalent clinical materials in oral restorations are ceramics and nano-resins.

2. Dental restorative materials

2.1 Resin

Most dental ceramics and hybrid resin composites have the potential to mimic the enamel and dentin, respectively. However, it has been suggested that moderate damage to teeth could be restored with resin composites. For the resin composites restorations, minimal preparation of teeth is required, reducing the likelihood of pulpal involvement and tooth fracture [11].

The filling resin composite can strengthen the remaining tooth structure in some cases. For example, cemented porcelain restorations are recommended for severely damaged, worn, or broken teeth in dental clinics. Besides, alumina and nano-hydroxyapatite are also widely used in dentistry [12]. Alumina is recommended because it has good fracture resistance, abrasion resistance, and high compressive strength. In addition, nano-hydroxyapatite is an essential part of teeth and bones. Therefore, it should achieve biomimetic properties in the restoration. Glass ionomer cement has a bactericidal effect because it releases fluoride and can stimulate hardened dentin [13]. In addition, these cements have properties comparable to dentin, thus realizing the concept of bionics. Glass-ionomer cements are used as restorative materials in deep class I or II cavities in pedodontics and restoration of class V cavities [14]. Glass-ionomer cements are not generally recommended in load-bearing posterior dentition due to low tensile strength. Therefore, in the context of mismatched elastic modulus between enamel and the direct restorative materials, more stresses may be transferred to teeth, leading to either tooth damage or failure of the restoration.

Nowadays, many clinicians take direct resin composite posterior restoration as their first choice in treating carious lesions or other tooth defects, including restoration of large cavities [15]. However, partial indirect restorations (inlay, onlay, and overlay) for excessive posterior tooth defects have started to replace direct resin composite restorations since the development of modern chairside computer-aided design/computer-aided manufacturing (CAD/CAM) systems [16].

One of the most important advancements in chairside CAD/CAM systems is the production of resin composite blocks [17, 18]. Paradigm MZ100, as an industrial polymerized version of direct resin composite (Z100), is the first product in this field [19]. Paradigm MZ100 contains bisphenol A-glycidyl methacrylate (Bis-GMA), triethylene glycol dimethacrylate, and 85% (by weight) zirconia-silica filler. Therefore, its degree of polymerization and mechanical properties are better than Z100 [20]. Later, a new resin composite block containing urethane dimethacrylate instead of Bis-GMA was produced under high temperature and pressure. This kind of resin was developed with the ambition of increasing the degree of polymerization [21, 22]. Recently, the flexibility and convenience of CAD/CAM resin composite are similar to resin composites, combined with durability, and surface finish characteristics are identical to ceramics. In addition, compared with glass ceramics, the resin composite block has minor wear on the relative teeth and can maintain its gloss for a longer time. Their non-fusion and composite-like properties make them easier to grind, polish, and adapt. Due to the less brittleness, the resin composite block has better edge characteristics. Furthermore, these materials produced less blunting on the drills during milling. They can also be repaired using resin composites with cutback or adding techniques. Besides, physical (color stability, water sorption, and water solubility) and mechanical (fracture-resistant, wear, compressive strength, hardness, and elastic modulus) properties of resin composite blocks were found better than that of conventional resin composite because of their higher degree of polymerization [23, 24].

Tunac et al. evaluate the 2 year clinical performance of computer-aided design/computer-aided manufacturing (CAD/CAM) resin composite inlay restorations in comparison with direct resin composite restorations. According to FDI standards, the results show that the 2 year clinical performance of CAD/CAM resin composite inlay restorations is similar to that of direct resin composite restorations. After 2 years of clinical trials, CAD/CAM resin composite inlays have shown exemplary performance in class II cavities and meet clinical needs [25].

Despite the above advantages, due to the high degree of polymerization, discoloration, tarnishing, and fracture of the resin composite block overtime after the repair, the adhesion failure of the cement interface is a problem that may need to be considered for its long-term clinical performance [26]. However, data on CAD/CAM resin composite partial crowns (inlays, onlays, and overlying) restorations are limited. Therefore, more clinical trials are needed to draw further conclusions about its clinical behavior.

2.2 Alloy

Porcelain fused to metal (PFM) restoration comprises a metal coping that supports overlying ceramic (**Figure 2**) [27]. PFM restorations have a long clinical track record. However, the PFM fixed partial denture (FPD) failure rates were 4% after 5 years, 12% after 10 years, and 32% after 15 years [28].

To date, PFM restorations remain the most widely and successfully used option for FPDs because their failure rates are often low (8–10% within 10 years) [29]. It was reported that clinical survival rates of FPDs are between 72% and 87% after 10 years, between 69% and 74% after 15 years, and 53% after 30 years [30, 31]. However, as is well-known, the metals used in PFM restorations can cause allergic or toxic reactions within soft or hard tissue [32]. Besides, PFM is known to cause graying of the gingival margin because of metal show-through [33].

Compatibility between the ceramic and the metal alloy is of paramount importance. PFM ceramic veneers consist of an opaque ceramic (e.g., a titanium oxide glass) that is required to mask the color of the underlying metal and provides the bond with the metal alloy [34, 35].

Opaque ceramics are combined with metal alloys through an oxide layer formed on the metal surface. This process is called degassing [36]. The degassing process can also remove contaminants on the surface of the alloy—coating dentin/body ceramics on opaque ceramics. Dentin ceramics can mimic natural dentin. Then apply the incisal ceramic to the dentin/body ceramic on the incisal third. The restoration can also be polished by using low-melting glazed ceramics or self-glazing.

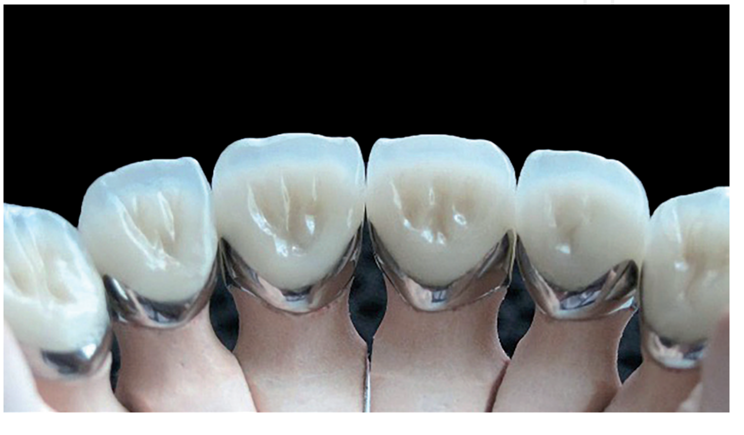

Figure 2.
Porcelain fused to metal (PFM). Porcelain fused to metal (PFM) restoration comprises a metal coping that supports overlying ceramic.

One of PFM restoration's main disadvantages is its inability to transmit light, thus having a negative effect on the aesthetic outcome of the restoration because it may appear dark in color [37]. This drawback is noticeable at the restoration's cervical area, where it is sometimes difficult to get enough room. Therefore, a sufficient tooth structure should be removed to accommodate the ceramic material, mask the underlying metal without overly modifying the restoration. In addition, the metal braces should stop 1 mm from the buccal finish line, and ceramic edges (shoulder ceramics) are recommended. Another disadvantage of a PFM restoration is allergic reactions in some patients to metal elements such as nickel in the metal alloy [32].

2.3 Ceramic

All-ceramic restorations refer to ceramic restorations made entirely of ceramic materials [38]. There are two kinds of all-ceramic restorations. One is monolithic (single layer), which composes of a single ceramic material. The other is a two-layer all-ceramic restoration which consists of a ceramic core material covered with a ceramic veneer [39, 40]. In the bi-layered, all-ceramic restoration, the ceramic core supports the restoration and gives it strength, while the veneer provides the restoration with its final shape, shade, and aesthetic [41]. Nevertheless, the veneer-core bond strength is considered one of the weakest links of the bi-layered all-ceramic restorations because they are prone to delamination and fracture [39]. Nowadays, with the increasing interest in aesthetics, a bi-layered all-ceramic restoration is widely applied in dentistry. However, the main disadvantages associated with this repair include delamination and fracture of the veneer [42]. In addition, it is sometimes difficult to achieve excellent occlusal contact with the structure of the opposing tooth. Finally, to achieve a lasting repair, the compatibility of the core and veneer materials is crucial [43].

When aesthetics is the priority, dental ceramics are the material of choice because they can successfully mimic the tooth substance's character (**Figure 3**) [44]. Ceramics can successfully simulate the visual characteristics of the tooth substance. Ceramics are biocompatible and inert material and have a high degree of intra-oral stability. Therefore, they can be safely used in the oral cavity. For example, the use of all-ceramic restorations has increased in recent years [45]. However, there are many ceramic materials and systems on the market that can be used in dentistry. The increased use of ceramics for restorative procedures and the need to improve clinical performance has led to the development and introduction of several new ceramic restorative materials and techniques [46].

Figure 3.
Ceramics. Ceramics can successfully simulate the visual characteristics of the tooth substance. Ceramics are biocompatible and inert material and have a high degree of intra-oral stability.

The all-ceramic restorations can be used as a bi-layered restoration, in which the more aesthetic ceramic veneer is the core or framework. They can also be used as full-contour (monolithic) restorations, which can be stained when required [47].

In the past decade, countless types of all-ceramic crown systems have been introduced unprecedentedly. Many of these systems have been criticized for their failure in restorations. It was reported that the survival rate of all-ceramic restorations ranges from 88–100% after 2–5 years of use and can still reach 97% after 5–15 years of use [48]. Although all-ceramic restorations have been greatly improved, zirconia is still the best all-ceramic restoration currently available. Since the end of the 1990s, due to many clinical and basic scientific research, this form of partially stabilized zirconia has been popularized for application in dentistry due to its excellent strength and excellent fracture resistance [49]. Currently, two main types of all-ceramic FDP systems have been proposed. The first of these systems involves the use of a single material to make full-contour crowns. For instance, a single crown in anterior teeth and premolars is made by reinforced glass materials successfully [50]. Further, a full-contour crown in the molar region is prepared with polycrystalline zirconia with improved translucency [51]. For the second system, porcelain and other glass materials are fused into a frame made of high-strength ceramics [52]. Dense sintered polycrystalline zirconia-based materials are expected to be used in FDP frameworks [53].

Yttrium partially stabilized tetragonal zirconia polycrystalline (Y-TZP), due to its superior mechanical properties and excellent fracture resistance, has drawn lots of attention in clinical applications. For instance, the fracture toughness of Y-TZP ranges from 5 to 10 MPa $m^{1/2}$, and bending strength varies from 900 to 1400 MPa [54]. Y-TZP-based systems are a recent addition to the high-strength, all-ceramic systems used for crowns and fixed partial dentures.

Zirconia is a white crystalline oxide of zirconium with high mechanical strength, toughness, and corrosion resistance. Besides, zirconia has excellent biocompatibility, which can significantly reduce dental plaque [55]. However, zirconia is degradable at low temperatures, and this is a gradual, spontaneous phenomenon. Recently, the introduction of stabilized zirconia is supposed to overcome this drawback and promote the application of zirconia in dental restorations [56].

Marchack et al. proposed a custom-designed powerful grinding ceramic core technology for all-ceramic crowns [57]. This technique can eliminate the porcelain covering of the zirconia inner crown and frame to reduce the incidence of chipping or cracking of the porcelain veneer. The fracture of veneering ceramic is the most common complication for zirconia restorations. Thus, some suggestions for optimizing the manufacturing process of zirconia-based FPDs have been issued, including changes to the firing protocol. It was recommended because it can reduce the chipping rate. In addition, zirconia-ceramic FDP shows more clinical problems like prolonged fracture of the veneer ceramic [58]. Therefore, dentists should pay more attention to zirconia-ceramic FDP generated by CAD/CAM system before all treatment procedures [29]. On the other hand, with the development of ceramics on zirconia, people invented the framework of lithium disilicate glass-ceramics.

Cercon ht (Dentsply Intl., York, PA, USA) is developed from a clinically proven Cercon-based yttria-stabilized zirconia material formulation. It represents a new generation of zirconia with excellent transparency and can be used for esthetic restorations without build-up porcelain [29]. In order to better reproduce the color of natural teeth, some zirconia-based materials have been developed as translucent [59]. Among them, zirconia is widely applied as crown and FDP without veneer or pressed ceramics. Zirconia has a high flexural strength of more than 1200 MPa and has excellent veneer properties [60]. In the dental clinic, zirconia has proven to be a durable and reliable frame material that can inhibit crack propagation and prevent catastrophic failure. However, there are clinical studies show that zirconia has an abrasive effect on the dentition, leading to excessive wear of the tooth structure [61]. The in vivo studies indicated that polished zirconia has higher wear resistance and lower resistance to wear than porcelain [62]. Currently, the new zirconia materials make the surface of the antagonist smooth, just like natural tooth enamel [63]. Although more and more research is focused on zirconia, there is still much to be understood about the production of zirconia and the production of zirconia inner crowns and frames. Dentists and researchers need further studies with larger sample sizes and extended follow-up periods to investigate the possible influencing factors of technical failures.

Ceria-stabilized tetragonal zirconia polycrystalline (Ce-TZP) is a newly developed ceramic material, which has not yet been used in the dental field. Its fracture toughness is 19 MPa $m^{1/2}$, which is significantly better than Y-TZP. However, Ce-TZP has lower bending strength and hardness than Y-TZP [64]. Then, Ce-TZP/alumina nanocomposite (Ce-TZP/A) was developed to improve the property of Ce-TZP [65]. Ce-TZP/A contains nano-sized Al_2O_3 particles and Ce-TZP particles dispersed in Ce-TZP grains and grain boundaries [66]. This uniform dispersion of alumina in the Ce-TZP matrix plays a positive role in grain growth. However, it also negatively affects flexural strength, hardness, and hydrothermal stability of tetragonal zirconia. As reported, Ce-TZP/A is currently the toughest zirconia material available, and its fracture toughness reaches 19 MPa $m^{1/2}$, and the flexural strength is high as 1400 MPa [65]. More importantly, Ce-TZP/A is entirely resistant to low-temperature aging degradation (LTAD), a critical drawback of Y-TZP [67]. The tremendous improvement of these characteristics is expected to extend the clinical application of dental ceramics to all-ceramic restorations and other areas, such as implant abutments, implants, removable denture bases, and components.

3. Conclusions

In conclusion, various dental restorative materials are available, and many appropriate materials are used to restore dental carious teeth. Among them, zirconia-based ceramics have been successfully introduced into the clinic due to acceptable biocompatibility, lower price compared with gold restorations and better appearance than traditional metal-ceramic restorations. In summary, zirconia restoration is an acceptable treatment option in restorative dentistry and a developing trend in esthetic dentistry.

Acknowledgements

This study was supported by the CSA Clinical Research Foundation for Young Scholars-All Ceramic Material Research Project (CSA-P2019-01).

Conflict of interest

The authors declare no conflict of interest.

Author details

Feng Luo[1]*, Hongyan Luo[2], Ruyi Li[1], Changxing Qu[1], Guang Hong[3,4]
and Qianbing Wan[1]

1 State Key Laboratory of Oral Diseases, National Clinical Research Center for Oral Diseases, West China School of Stomatology, Sichuan University, Chengdu, China

2 Department of Psychological Counseling, People's Hospital of Lianhua County, Jiangxi Province, China

3 Liaison Center for Innovative Dentistry, Graduate School of Dentistry, Tohoku University, Sendai, Japan

4 Faculty of Dental Medicine, Department of Prosthetic Dentistry, Airlangga University, Surabaya, Indonesia

*Address all correspondence to: luofeng0122@scu.edu.cn

References

[1] Liu CH, Jeyaprakash N, Yang CH. Material characterization and defect detection of additively manufactured ceramic teeth using non-destructive techniques. Ceramics International. 2020

[2] Yadav K, Prakash S. Dental caries: A microbiological approach. Journal of Clinical Infectious Diseases & Practice. 2017;**2**(1):1-15

[3] Coll PP, Lindsay A, Meng J, et al. The prevention of infections in older adults: Oral health. Journal of the American Geriatrics Society. 2020;**68**(2):411-416

[4] Ruan Q, Zhang Y, Yang X, et al. An amelogenin–chitosan matrix promotes assembly of an enamel-like layer with a dense interface. Acta Biomaterialia. 2013;**9**(7):7289-7297

[5] Xue J, Zavgorodniy AV, Kennedy BJ, et al. X-ray microdiffraction, TEM characterization and texture analysis of human dentin and enamel. Journal of Microscopy. 2013;**251**(2):144-153

[6] Lee EY, Kim ES, Kim KW. Scanning electron microscopy and energy dispersive X-ray spectroscopy studies on processed tooth graft material by vacuum-ultrasonic acceleration. Maxillofacial Plastic and Reconstructive Surgery. 2014;**36**(3):103

[7] Lei C, Jiyao L, HKXH, et al. Demineralization and remineralization. In: Dental Caries. Berlin, Heidelberg: Springer; 2016. pp. 71-83

[8] Khan AS, Syed MR. A review of bioceramics-based dental restorative materials. Dental Materials Journal. 2019;**38**(2):163-176

[9] Santheep PC, Kumar R, Simon EP, et al. Biomimetics in conservative dentistry and endodontics. Dental Bites. 2017:32

[10] Priyadarsini S, Mukherjee S, Bag J, et al. Application of nanoparticles in dentistry: Current trends. In: Nanoparticles in Medicine. Singapore: Springer; 2020. pp. 55-98

[11] Sabbagh J, McConnell RJ, McConnell MC. Posterior composites: Update on cavities and filling techniques. Journal of Dentistry. 2017;**57**:86-90

[12] Mazumder S, Nayak AK, Ara TJ, et al. Hydroxyapatite composites for dentistry. Applications of Nanocomposite Materials in Dentistry. 2019:123-143

[13] Sidhu SK, Nicholson JW. A review of glass-ionomer cements for clinical dentistry. Journal of Functional Biomaterials. 2016;**7**(3):16

[14] Heck K, Frasheri I, Diegritz C, et al. Six-year results of a randomized controlled clinical trial of two glass ionomer cements in class II cavities. Journal of Dentistry. 2020;**97**:103333

[15] Lempel E, Lovász BV, Bihari E, et al. Long-term clinical evaluation of direct resin composite restorations in vital vs. endodontically treated posterior teeth—Retrospective study up to 13 years. Dental Materials. 2019;**35**(9):1308-1318

[16] Amesti-Garaizabal A, Agustín-Panadero R, Verdejo-Solá B, et al. Fracture resistance of partial indirect restorations made with CAD/CAM technology. A systematic review and meta-analysis. Journal of Clinical Medicine. 2019;**8**(11):1932

[17] Alamoush RA, Satterthwaite JD, Silikas N, et al. Viscoelastic stability of pre-cured resin-composite CAD/CAM structures. Dental Materials. 2019;**35**(8):1166-1172

[18] Choi BJ, Yoon S, Im YW, et al. Uniaxial/biaxial flexure strengths and elastic properties of resin-composite block materials for CAD/CAM. Dental Materials. 2019;**35**(2):389-401

[19] Tsujimoto A, Barkmeier WW, Takamizawa T, et al. Influence of thermal cycling on flexural properties and simulated wear of computer-aided design/computer-aided manufacturing resin composites. Operative Dentistry. 2017;**42**(1):101-110

[20] Tekce N, Pala K, Demirci M, et al. Influence of different composite materials and cavity preparation designs on the fracture resistance of mesio-occluso-distal inlay restoration. Dental Materials Journal. 2016;**35**(3):523-531

[21] Phan AC, Tang M, Nguyen JF, et al. High-temperature high-pressure polymerized urethane dimethacrylate—Mechanical properties and monomer release. Dental Materials. 2014;**30**(3):350-356

[22] Béhin P, Stoclet G, Ruse ND, et al. Dynamic mechanical analysis of high pressure polymerized urethane dimethacrylate. Dental Materials. 2014;**30**(7):728-734

[23] Sulaiman TA. Materials in digital dentistry—A review. Journal of Esthetic and Restorative Dentistry. 2020;**32**(2):171-181

[24] Moldovan M, Balazsi R, Soanca A, et al. Evaluation of the degree of conversion, residual monomers and mechanical properties of some light-cured dental resin composites. Materials. 2019;**12**(13):2109

[25] Tunac AT, Celik EU, Yasa B. Two-year performance of CAD/CAM fabricated resin composite inlay restorations: A randomized controlled clinical trial. Journal of Esthetic and Restorative Dentistry. 2019;**31**(6): 627-638

[26] Stanislawczuk R, Pereira F, Muñoz MA, et al. Effects of chlorhexidine-containing adhesives on the durability of resin–dentine interfaces. Journal of Dentistry. 2014;**42**(1):39-47

[27] Abrisham SM, Tafti AF, Kheirkhah S, et al. Shear bond strength of porcelain to a base-metal compared to zirconia core. Journal of Dental Biomaterials. 2017;**4**(1):367

[28] Zarone F, Russo S, Sorrentino R. From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. Dental Materials. 2011;**27**(1):83-96

[29] Pradeep C, Gupta S, Sisodia S. Zirconia in dentistry: An overview. Guident. 2020;**13**(10)

[30] Ahmed KE, Li KY, Murray CA. Longevity of fiber-reinforced composite fixed partial dentures (FRC FPD)—Systematic review. Journal of Dentistry. 2017;**61**:1-11

[31] von Stein-Lausnitz M, Nickenig HJ, Wolfart S, et al. Survival rates and complication behaviour of tooth implant–supported, fixed dental prostheses: A systematic review and meta-analysis. Journal of Dentistry. 2019;**88**:103167

[32] Levi L, Barak S, Katz J. Allergic reactions associated with metal alloys in porcelain-fused-to-metal fixed prosthodontic devices—A systematic review. Quintessence International-Journal of Practical Dentistry-English Edition. 2012:871

[33] Monaco C, Caldari M, Scotti R. Clinical evaluation of 1132 zirconia-based single crowns: A retrospective cohort study from the AIOP clinical research group. International Journal of Prosthodontics. 2013;**26**(5)

[34] Alikhasi M, Monzavi A, Ebrahimi H, et al. Debonding time and

dental pulp temperature with the Er, Cr: YSGG laser for debonding feldespathic and lithium disilicate veneers. Journal of Lasers in Medical Sciences. 2019;**10**(3):211

[35] Zhang Y, Kelly JR. Dental ceramics for restoration and metal veneering. Dental Clinics. 2017;**61**(4):797-819

[36] Yoo SY, Kim SK, Heo SJ, et al. Effects of bonding agents on metal-ceramic bond strength of Co-Cr alloys fabricated by selective laser melting. Materials. 2020;**13**(19):4322

[37] Trushkowsky RD. Esthetic and functional consideration in restoring endodontically treated teeth. Dental Clinics. 2011;**55**(2):403-410

[38] Warreth A, Elkareimi Y. All-ceramic restorations: A review of literature. Saudi Dental Journal. 2020

[39] Li SL, Zhang Q, Wu FF, et al. Research progress on all ceramic zirconia core/veneer interface: A review. Science of Advanced Materials. 2020;**12**(1):5-14

[40] Toyama DY, Alves LMM, Ramos GF, et al. Bioinspired silica-infiltrated zirconia bilayers: Strength and interfacial bonding. Journal of the Mechanical Behavior of Biomedical Materials. 2019;**89**:143-149

[41] Xie Z, Wang X, Chen J, et al. The effects of core material and cooling rate on fabrication defects in the veneer of bi-layered all-ceramic systems. Ceramics International. 2019;**45**(13):15876-15882

[42] Aboushelib MN, De Jager N, Kleverlaan CJ, et al. Microtensile bond strength of different components of core veneered all-ceramic restorations. Dental Materials. 2005;**21**(10):984-991

[43] Kang W, Park JK, Kim SR, et al. Effects of core and veneer thicknesses on the color of CAD-CAM lithium disilicate ceramics. The Journal of Prosthetic Dentistry. 2018;**119**(3):461-466

[44] Shahmiri R, Standard OC, Hart JN, et al. Optical properties of zirconia ceramics for esthetic dental restorations: A systematic review. The Journal of Prosthetic Dentistry. 2018;**119**(1):36-46

[45] Tezulas E, Yildiz C, Kucuk C, et al. Current status of zirconia-based all-ceramic restorations fabricated by the digital veneering technique: A comprehensive review. International Journal of Computerized Dentistry. 2019;**22**(3):217-230

[46] Al Hamad KQ, Obaidat II, Baba NZ. The effect of ceramic type and background color on shade reproducibility of all-ceramic restorations. Journal of Prosthodontics. 2020;**29**(6):511-517

[47] Altamimi AM, Tripodakis AP, Eliades G, et al. Comparison of fracture resistance and fracture characterization of bilayered zirconia/fluorapatite and monolithic lithium disilicate all ceramic crowns. International Journal of Esthetic Dentistry. 2014;**9**(1):98-110

[48] Moscovitch M. Consecutive case series of monolithic and minimally veneered zirconia restorations on teeth and implants: Up to 68 months. International Journal of Periodontics & Restorative Dentistry. 2015;**35**(3)

[49] Sulaiman TA, Abdulmajeed AA, Shahramian K, et al. Effect of different treatments on the flexural strength of fully versus partially stabilized monolithic zirconia. The Journal of Prosthetic Dentistry. 2017;**118**(2):216-220

[50] Beuer F, Stimmelmayr M, Gueth JF, et al. In vitro performance of full-contour zirconia single crowns. Dental Materials. 2012;**28**(4):449-456

[51] Rosentritt M, Preis V, Behr M, et al. Fatigue and wear behaviour of zirconia materials. Journal of the Mechanical Behavior of Biomedical Materials. 2020;**110**:103970

[52] Takeichi T, Katsoulis J, Blatz MB. Clinical outcome of single porcelain-fused-to-zirconium dioxide crowns: A systematic review. The Journal of Prosthetic Dentistry. 2013;**110**(6): 455-461

[53] Zarone F, Di Mauro MI, Spagnuolo G, et al. Fourteen-year evaluation of posterior zirconia-based three-unit fixed dental prostheses: A Prospective clinical study of all ceramic prosthesis. Journal of Dentistry. 2020;**101**:103419

[54] Ab-Ghani Z. Non-aqueous sol-gel derived calcia partially stabilized zirconia: Synthesis and characterizations. Malaysian Journal of Microscopy. 2020;**16**(1)

[55] Yu T, Zhang Z, Liu Q, et al. Extrusion-based additive manufacturing of yttria-partially-stabilized zirconia ceramics. Ceramics International. 2020;**46**(4):5020-5027

[56] Camposilvan E, Leone R, Gremillard L, et al. Aging resistance, mechanical properties and translucency of different yttria-stabilized zirconia ceramics for monolithic dental crown applications. Dental Materials. 2018;**34**(6):879-890

[57] Marchack BW, Sato S, Marchack CB, et al. Complete and partial contour zirconia designs for crowns and fixed dental prostheses: A clinical report. The Journal of Prosthetic Dentistry. 2011;**106**(3):145-152

[58] Vigolo P, Mutinelli S. Evaluation of zirconium-oxide-based ceramic single-unit posterior fixed dental prostheses (FDPs) generated with two CAD/CAM systems compared to porcelain-fused-to-metal single-unit posterior FDPs: A 5-year clinical prospective study. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2012;**21**(4): 265-269

[59] Capa N, Tuncel I, Tak O, et al. The effect of luting cement and titanium base on the final color of zirconium oxide core material. Journal of Prosthodontics. 2017;**26**(2):136-140

[60] Tabatabaian F. Color in zirconia-based restorations and related factors: A literature review. Journal of Prosthodontics. 2018;**27**(2):201-211

[61] Huang Z, Huang J, Li C, et al. The application of 3D printed self-glazed zirconia for full-mouth rehabilitation in a patient with severely worn dentition: A case report. Advances in Applied Ceramics. 2020;**119**(5-6):305-311

[62] Zhang F, Spies BC, Vleugels J, et al. High-translucent yttria-stabilized zirconia ceramics are wear-resistant and antagonist-friendly. Dental Materials. 2019;**35**(12):1776-1790

[63] Shi A, Wu Z, Huang J, et al. Wear performance of self-glazed zirconia crowns with different amount of occlusal adjustment after 6 months of clinical use. Advances in Applied Ceramics. 2018;**117**(8):445-451

[64] Abi CBE. Toughening mechanisms in dental composites. Toughening Mechanisms in Composite Materials. 2015:321-337

[65] Hagiwara Y, Nakajima K. Application of Ce-TZP/Al_2O_3 nanocomposite to the framework of an implant-fixed complete dental prosthesis and a complete denture. Journal of Prosthodontic Research. 2016;**60**(4):337-343

[66] Omori S, Komada W, Yoshida K, et al. Effect of thickness of

zirconia-ceramic crown frameworks on strength and fracture pattern. Dental Materials Journal. 2013;**32**(1):189-194

[67] Hussein AI, Ab-Ghani Z, Che Mat AN, et al. Synthesis and Characterization of Spherical Calcium Carbonate Nanoparticles Derived from Cockle Shells. Applied Sciences. 2020;**10**(20):7170