Translucency and Mechanical Property of Different Translucent Zirconia Thicknesses Compared to Lithium Disilicate Ceramic

Rinrada Arayakhun[1], Nuttaphon Kittikundecha[1]*, Sirichan Chiaraputt[1], Niyom Thamronganankul[2], Vibul Pisarnkobrit[1], Apirat Ritthiti[1], Charnsak Sukajintanakarn[1], Katanyoo Limchaikul[1]

1. Department of Conservative Dentistry and Prosthodontics, The Faculty of Dentistry, Srinakharinwirot University, Bangkok, Thailand.
2. Department of Prosthodontics, The Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand.

Abstract

The purpose of this study was to investigate the effect of thickness on translucency and mechanical property of translucent zirconia compared to lithium disilicate ceramic for proper selection of monolithic crowns.

IPS e.max CAD HT and UTML, both shaded A2, were designed and fabricated as circular disc-shaped specimens (n=30), with a diameter of 12.0 mm, and subdivided into 6 groups: IPS e.max CAD HT and UTML corresponding to thicknesses of 0.8, 1.0, and 1.5 mm (5 discs/group). Their L*a*b values were measured using spectrophotometer, and the TP was calculated. After that, biaxial flexural strength was tested using universal testing machine.

Translucency of IPS e.max CAD HT at 1.5 mm was statistically significantly lower than UTML at 0.8 and 1.0 mm ($p<0.01$). No statistical difference was seen between biaxial flexural strengths of IPS e.max CAD HT at 1.5 mm and UTML at 1.0 mm ($p=0.25$).

According to the indications of manufacturers, fabricating posterior monolithic crown with UTML preserved more of the tooth structure and also provided higher translucency rather than IPS e.max CAD HT, while they were equally strong for such thicknesses.

Experimental article (J Int Dent Med Res 2023; 16(2): 504-509)

Keywords: Translucent zirconia, translucency parameter, biaxial flexural strength.

Received date: 25 March 2023 **Accept date:** 19 April 2023

Introduction

In recent years, the increased demand for esthetics has led to the use of metal-free materials as a substitute for metal-ceramic restorations. The opacity of the metal substructure in PFM crowns and the mismatch of CTE between a metal substructure and veneering porcelain, which can cause veneer chipping, remains a major drawback of PFM restorations. Due to their ability to match the optical properties of the adjacent natural dentition, all-ceramic restorations have been widely used.[1,2] Recently, the monolithic zirconia crown has become popular among dentists as an alternative material for posterior restorations to avoid undesired veneer chipping.[3] Zirconia is a highly resistant polycrystalline ceramic characterized by favorable mechanical properties such as high flexural strength and fracture toughness.[1,4] However, the high opacity and whitish appearance of monolithic zirconia crowns are limitations for mimicking the natural appearance of human teeth in areas of esthetic concern. Lithium disilicate ceramic is one of the most particle-filled glass ceramics, which provides very good esthetic appearance. It is about 30% higher in translucence than traditional zirconia.[5,6] Even though lithium disilicate ceramic is preferable to zirconia for anterior restorations, traditional 3Y-TZP zirconia has greater flexural strength and fracture toughness than that of lithium disilicate ceramic.[6] This has driven the new generation of zirconia materials.

The optical properties of zirconia have been improved by multiple methods such as increasing the sintering temperature above 1500°C to provide larger grain size and diminish impurities and pores, reducing the alumina oxide content below 0.05 wt%, and increasing the yttrium oxide content to enhance the cubic phase.[7-9] "Katana" (Kuraray Noritake, Japan) was

Corresponding author:
Nuttaphon Kittikundecha, DDS, PhD
Department of Conservative Dentistry and Prosthodontics,
The Faculty of Dentistry, Srinakharinwirot University
(Prasarnmit Campus), No.114 Sukhumvit 23, Wattana District,
Bangkok, Thailand 10110
E-mail: nuttaphon_kit@hotmail.com

first introduced in 2015 as a high-translucent multilayered zirconia. It was divided into 3 grades: ultra-translucent multilayered zirconia (UTML) comprising 7.55 wt% or 5.4 mol% Y_2O_3 – which was graded as 5Y-PSZ, super-translucent multilayered zirconia (STML) comprising 6.75 wt% or 4.8 mol% Y_2O_3 – which was graded as 4Y-PSZ, and multilayered zirconia (ML) comprising 5.2 wt% or 3.7 mol% Y_2O_3.[7] According to the manufacturer, these three materials are designed in different shade gradients from incisal to cervical area to mimic natural human teeth, and can cover all monolithic restorative applications.[10] However, Kolakarnprasert N et al.[7] reported that only different types and amounts of pigment were found between dentin and enamel layers, resulting in different colors, so there were no significant differences in translucency and mechanical properties. Although 5Y-PSZ had higher light transmittance than 3Y-TZP, its flexural strength and fracture toughness lay between IPS e.max CAD groups and 3Y-TZP.[6]

The translucency parameter (TP) is a widely used measure to determine the translucency of dental ceramics. TP was calculated according to the color difference of the objects over a black-and-white background. A higher TP value indicates higher translucency of the dental ceramic.[2,11]

Biaxial flexural strength (σ), that is accepted by the American Society for Testing and Materials and International Organization for Standardization, is frequently used to determine the strength of circular disc-shaped specimens and is suitable for brittle materials like dental ceramics.[12] The biaxial flexural strength test can overcome the undesirable edge failure problems, which are the drawbacks of the 3-point and 4-point bending tests, and thus ensures a reliable strength measurement for dental ceramics.[13]

Nowadays, there is increasing demand for adequate esthetic qualities and sufficient strength for both anterior and posterior restorations. Therefore, highly translucent zirconia has received great attention from both dentists and researchers. However, the proper thicknesses of highly translucent zirconia for fabricating monolithic crowns remain unclear. So, the objective of this study was to investigate the effect of thickness on the translucency and mechanical properties of translucent zirconia compared to lithium disilicate ceramic for proper material selection for monolithic crowns to achieve the maximum esthetic appearance and preserve the natural tooth structures. The null hypothesis was that the thicknesses would not affect the translucency and biaxial flexural strength of IPS e.max CAD HT and UTML zirconia.

Materials and methods

Sample preparation

Blocks of lithium disilicate ceramic (IPS e.max CAD HT shade A2, Ivoclar Vivadent AG, Schaan, Liechtenstein) were designed by CAD software and fabricated using a CAM machine (VHF N4, VHF, Ammerbuch, Germany) as circular disc-shaped specimens (n = 30), with a diameter of 12.0 mm, subdivided into 3 groups corresponding to thicknesses of 0.8, 1.0, and 1.5 mm (5 discs/group). A natural-shade glaze (IPS Ivocolor glaze paste, Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to the tested surface of each specimen. IPS e.max CAD HT specimens were fully crystallized and glaze-fired using firing furnaces (Programat P300 furnace, Ivoclar Vivadent AG, Schaan, Liechtenstein) according to the manufacturer's recommendations. Discs of translucent zirconia (Katana UTML zirconia shade A2, Kuraray Noritake, Tokyo, Japan) were designed by CAD software (each specimen was placed on the enamel layer of the disc) and milled using a CAM machine (VHF S2, VHF, Ammerbuch, Germany) as circular disc-shaped specimens (n = 30). After the UTML zirconia specimens were milled, they were sintered by zirconia sintering furnaces (Sintra Plus, Shenpaz Dental Ltd., Migdal HaEmek, Israel) according to the manufacturer’s recommendation. Clear glaze paste (Cerabien ZR glaze paste, Kuraray Noritake, Tokyo, Japan) was applied to the tested surface of each specimen. Glaze-firing of UTML zirconia specimens was achieved by zirconia firing furnaces (Zirconia firing furnaces, Multimat NTX, Dentsply Sirona, NY, USA). The final dimension was 12.0 mm in diameter with thicknesses of 0.8, 1.0, and 1.5 mm (5 discs per group). The specimens were evaluated with digital vernier calipers (AOS Absolute Digimatic Vernier Caliper, Mitutoyo, Kanagawa, Japan) accurate to within 0.01 mm (Figure 1,2). The thickness of the specimens was selected according to the manufacturer’s indications for anterior and posterior monolithic crowns. Information of materials that have been used in this study are shown in Table 1.

Figure 1. Circular disc-shaped specimens of IPS e.max CAD HT.

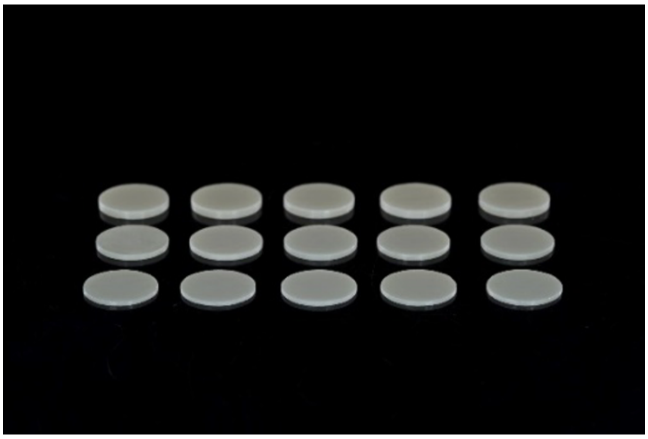

Figure 2. Circular disc-shaped specimens of Katana UTML zirconia.

Translucency test

L*a*b values of the IPS e.max CAD HT and Katana UTML zirconia specimens were measured against a black-and-white background by a dental spectrophotometer (VITA Easyshade V, Vita Zahnfabrik, Bad Säckingen, Germany) with a light beam generated by a light-emitting diode (LED) with a 400- to 700-nm specular output. The light source's illumination corresponded to standard illuminant D65. The tip of the dental spectrophotometer was placed in the center of the specimen. Each specimen was measured three times. Calibration was done with a calibration plate (Figure 3). The translucency parameter was calculated using the following equation: $TP = [(L^*_B – L^*_W)^2 + (a^*_B – a^*_W)^2 + (b^*_B – b^*_W)^2]^{1/2}$ where TP refers to the translucency parameter, L* refers to the brightness, a* refers to redness to greenness, and b* refers to yellowness to blueness. The subscripts B and W refer to the color coordinates on black backgrounds and white backgrounds, respectively. A higher TP value indicates higher translucency of each specimen.

Figure 3. L*a*b values measurement using Vita Easyshade V.

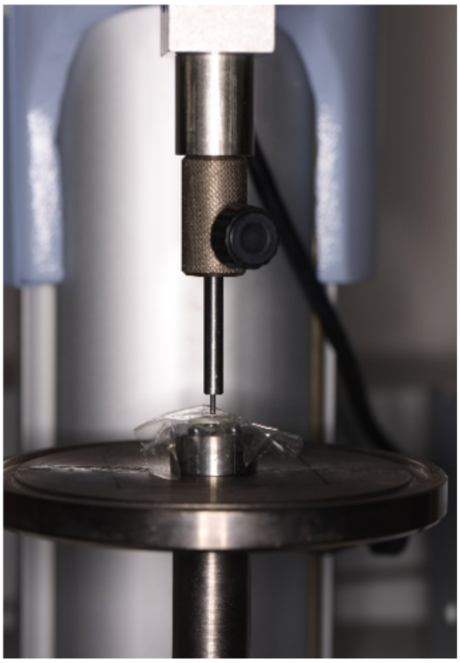

Figure 4. Biaxial flexural strength test (Piston-on-three-ball) using the EZ test universal testing machine.

Biaxial flexural strength test (piston-on-three-ball)

After measuring the translucency parameter, the specimens were placed on the piston-on-three-ball apparatus, which consisted of three spherical steel balls with a diameter of 3.0 mm positioned 120° apart on a support circle with a diameter of 11.0 mm. The specimens were compressed with a flat-ended piston with a diameter of 1.4 mm. Polyethylene sheets with a thickness of 50 µm were placed between the loading piston and the upper surface of the specimen and between the bottom surface of the specimen and the three spherical balls for force distribution. The load was applied from the universal testing machine (EZ test, Shimadzu Corporation, Kyoto, Japan) through the loading piston at the center of the specimen at a crosshead speed of 1.0 mm/min until fracture (Figure 4). The biaxial flexural strength was calculated using the following equation: $\sigma = -0.2387P(X-Y)/t^2$ according to ISO 6872-2015,[14] where σ refers to biaxial flexural strength in MPa, P refers to the load at failure in newtons, and t refers to the thickness of the specimen in mm. Meanwhile, X and Y are given by the following equations: $X = (1+v)\ln(r_2/r_3)^2+[(1-v)/2](r_2/r_3)^2$ and $Y = (1+v)[1+\ln(r_1/r_3)^2]+(1-v)(r_1/r_3)^2$ in which v is Poisson's ratio of ceramics (assuming 0.25 for lithium disilicate and 0.26 for translucent zirconia),[15,16] r_1 is the radius of the support circle in mm, r_2 is the radius of the loading piston in mm, and r_3 is the radius of the specimen.

Results

The average values of the translucency parameter and biaxial flexural strength of UTML zirconia and IPS e.max CAD HT were summarized in Table 1,2,3.

Material	Manufacturer	Lot no.	Composition
IPS e.max CAD HT	Ivoclar Vivadent	Z027TP	SiO_2 57-80%, Li_2O 11-19%, K_2O 0-13%, P_2O_5 0-11%, ZrO_2 0-8%, ZnO 0-8%, Al_2O_3 0-5%, MgO 0-5%, coloring oxides 0-8% by weight
UTML zirconia	Kuraray Noritake Dental inc.	EHIAV	ZrO_2+ HfO_2 87-92%, Y_2O_3 8-11%, Other oxides 0-2%

Table 1. Restorative materials used in the research.

Types of ceramic	Thicknesses (mm)		
	0.8	1.0	1.5
IPS e.max CAD HT	$22.77^A \pm 0.03564$	$19.31^B \pm 0.02000$	$14.06^C \pm 0.05899$
UTML zirconia	$15.88^D \pm 0.08620$	$14.89^E \pm 0.02966$	$10.10^F \pm 0.01483$

Table 2. Mean and standard deviations (SD) of translucency parameter values.
The same letters indicate that there is no significant difference between the groups. (p-value > 0.05).

Types of ceramic	Thicknesses (mm)		
	0.8	1.0	1.5
IPS e.max CAD HT	$167.72^a \pm 1.66714$	$202.52^b \pm 0.83354$	$326.75^c \pm 2.02787$
UTML zirconia	$208.46^b \pm 2.16817$	$319.76^c \pm 1.25936$	$398.15^d \pm 1.74291$

Table 3. Mean and standard deviations (SD) of biaxial flexural strength values (MPa).
The same letters indicate that there is no significant difference between the groups. (p-value > 0.05).

A decrease in the translucency parameter and an increase in biaxial flexural strength were observed when the thicknesses of the two ceramics were increased. The one-way ANOVA demonstrated statistically significant differences in the translucency parameter and biaxial flexural strength among various thicknesses within the same ceramic type. ($p<0.01$) The results of the independent t-test showed the translucency of IPS e.max CAD HT was statistically significantly higher than UTML zirconia ($p<0.01$), while the biaxial flexural strength of IPS e.max CAD HT was statistically significantly lower than that of UTML zirconia at the same thicknesses. ($p<0.01$) IPS e.max CAD HT at 0.8 and 1.0 mm had statistically significantly higher translucency parameters than UTML zirconia at all thicknesses ($p<0.01$), while the translucency of IPS e.max CAD HT at 1.5 mm was statistically significantly lower than UTML zirconia at 0.8 and 1.0 mm. ($p<0.01$) No statistical difference was seen between the biaxial flexural strengths of IPS e.max CAD HT at 1.0 mm and UTML zirconia at 0.8 mm ($p=0.25$), or IPS e.max CAD HT at 1.5 mm and UTML zirconia at 1.0 mm. ($p= 0.25$)

Discussion

The null hypothesis was rejected as the results showed that the translucency and biaxial flexural strength of dental ceramics depend on the type of ceramic and the thickness of the restorations. This study showed that a decrease in the translucency parameter was observed when the thickness of two ceramics was increased. In fact, there is an increase in light absorption when passing through thick objects and, thus, lower light reflection to the human eyes, resulting in lower L* values.[17,18]

Although the optical properties of ultra-translucent multi-layered zirconia were improved, this study showed that the translucency of UTML zirconia was statistically significantly lower than IPS e.max CAD HT at the same thicknesses, in accordance with the previous studies of Baldissara P et al.[5], Harianawala HH et al.[19], and Kwon SJ et al.[20] UTML zirconia, which was used in this study, can have its optical properties developed by adding 5.4% mol yttrium oxide to enhance the cubic content (75% by weight), namely 5Y-PSZ.[7,9,21] The traditional 3Y-TZP has tetragonal grains sized approximately 280–360 nm, whereas the 5Y-PSZ consists of bimodal grains sized 543–1680 nm with larger cubic grains sized 1.2 μm, which are embedded in tetragonal grain structures.[6] Furthermore, increasing the sintering temperature to 1550°C for UTML zirconia can also provide higher cubic content and larger grain size.[7] According to the larger grain of cubic crystals, the reduction in grain boundary light scattering enhances the translucency of 5Y-TZP.[6,7,22] The cubic crystal is isotropic which provides continuity of the refractive index at the grain boundaries. This isotropic characteristic causes more light transmission than that of an anisotropic tetragonal crystal.[7,21-23] Finally, the refractive index mismatch between alumina (n = 1.765) and zirconia (n = 2.175) can cause light scattering because the material could be opaque when the refractive index between the phases is 1.1 or more.[8,24] Increasing the translucency of 5Y-PSZ is done by decreasing the amount of alumina oxide because the lower the alumina content, the greater the light transmission.[8] Kolakarnprasert N et al.[7] reported that alumina oxide and pores were not detected in UTML zirconia. However, UTML zirconia does not only consist of 75% by weight of cubic content but also has 25% by weight of tetragonal crystal. Tetragonal crystal is birefringent, resulting in a discontinuity of the refractive index at the grain boundaries that can cause light scattering.[21] On the other hand, the microstructure of fully-crystallized lithium disilicate consists of approximately 70% fine-grain lithium disilicate crystals, which are embedded in a glassy matrix without any pores that allow light scattering.[25,26] Kim HK et al.[8] reported that the IPS e.max CAD HT contained Zn 3.9805% by weight, which supports the crystallization process.[27] In addition, small amounts of Sr 0.0604% by weight and Ce 5.7366% by weight can raise the refractive index of the glass matrix (n = 1.5) to match that of lithium disilicate (n = 1.55), making it highly translucent by reducing light scattering.[27] Therefore, the translucence of IPS e.max CAD HT was higher than for UTML zirconia.

Furthermore, this study showed that IPS e.max CAD HT had statistically significantly lower biaxial flexural strength than UTML zirconia at the same thicknesses. Under the effects of mechanical and thermal stress, UTML zirconia can undergo the phase transformation from a tetragonal phase to a more stable monoclinic phase, called "transformation toughening". The 4–5% larger volume of the monoclinic crystal would create compressive stress to block the propagation of cracks within the material.[4] IPS e.max CAD HT lacks this phase transformation, which would impede crack propagation within the material.

According to the indications of the manufacturer for monolithic crowns,[10,26] this study showed that fabricating posterior crowns with 1 mm thick UTML zirconia preserved more of the tooth structure and also provided higher translucency than 1.5 mm thick IPS e.max CAD HT, while they were equally strong for such thicknesses. UTML zirconia can be a better substitute for IPS e.max CAD for posterior monolithic crowns in the esthetic zone, especially premolars, because of its superior optical properties. But due to the incorporation of intraoral water constituents into the zirconia lattice, this process is commonly referred to as low temperature degradation (LTD).[28] Kolakarnprasert N et al.[7] reported that alumina oxide, which plays a crucial role in preventing zirconia from LTD, was not detected in UTML zirconia. Phase transformation was also not found in UTML zirconia after hydrothermal aging, which is able to simulate at least 30 years *in vivo*. Therefore, using UTML zirconia as the restoration for patients with severe malocclusions and parafunctional habits should be carefully considered. In fabricating anterior monolithic crowns, this study found that 1 mm thick IPS e.max CAD HT provided higher translucency than 0.8 mm thick UTML zirconia while they were equally strong for such thicknesses. IPS e.max CAD HT better simulated the natural appearance and optical properties of human teeth than UTML zirconia, but in some cases, UTML zirconia can be an alternative material for anterior monolithic crowns such as masking dark abutment teeth or a metal core, and in patients with opaque adjacent teeth. However, in the clinical aspect, the ceramic restorations are surface-treated and achieved effective resin bonding on the abutment teeth to increase their biaxial flexural strengths, especially in the case of lithium disilicate glass ceramics, which is treated with 5 – 9% hydrofluoric acid (HF) followed by silane methacrylate monomer.[29] The surface treatment using 25 μm alumina airborne-particle or 30 μm silica-coated alumina particles abrasion combined with 10- Methacryloyloxydecyl dihydrogen phosphate (10- MDP) monomer containing primer agents, such as Monobond Plus enhance both bond strength and bond durability for zirconia.[30,31] Alumina particle blasting is an efficient method, which increases micro-porosities of the zirconium dioxide surface, without damaging zirconia substructure.[31] Therefore, further studies on the biaxial flexural strength of surface-treated and bonded lithium disilicate ceramic and translucent zirconia to abutment teeth are needed.

Conclusion

Within the limitations of this study, it was concluded that according to the indications of manufacturers, fabricating anterior monolithic crown with IPS e.max CAD HT provided higher translucency than UTML zirconia, and restoring posterior monolithic crown with UTML zirconia preserved more tooth structure and also provided higher translucency rather than IPS e.max CAD HT, while they were equally strong for such thicknesses.

Declaration of Interest

The authors have no conflicts of interest to declare.

Acknowledgements

Funding was provided by the Faculty of Dentistry, Srinakharinwirot University (Grant No. 346/2565).

References

1. Komine F, Blatz BM, Matsumura H. Current status of zirconia-based fixed restorations. J Oral Sci 2010;52(4):531-9.
2. Li Q, Yu H, Wang YN. Spectrophotometric evaluation of the optical influence of core build-up composites on all-ceramic material. Dent Mater 2009;25(2):158-165.
3. Zarone F, Russo S, Sorrentino R. From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. Dent Mater 2011;27:83-96.
4. Zarone F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: A narrative review. BMC Oral Health 2019;19(1):134.
5. Baldissara P, Llukacej A, Ciocca L, Valandro FL, Scotti R. Translucency of zirconia copings made with different cad/cam systems. J Prosthet Dent 2010;104(1):6-12.
6. Kim HK. Optical and mechanical properties of highly translucent dental zirconia. Materials (Basel) 2020;13(15):3395.
7. Kolakarnprasert N, Kaizer MR, Do Kyung K, Zhang Y. New multi-layered zirconias: Composition, microstructure and translucency. Dent Mater 2019;35(5):797-806.
8. Kim HK. Effect of a rapid-cooling protocol on the optical and mechanical properties of dental monolithic zirconia containing 3–5 mol% Y_2O_3. Materials (Basel) 2020;13(8):1923.
9. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater 2014;30(10):1195-1203.
10. Katana zirconia multi-layered zirconia disc series technical guide. Available at "https://www.kuraraynoritake.eu/pub/media/pdfs/21599_1_Katana_discs_Technical_Guide_LR_21.pdf?fbclid=IwAR3FyWYHRd7EA13IG661ASHlPJxuNcG2v1b3demLaBOtTB1Xms7h5LgC9wM". Accessed July 20, 2021.
11. Salas M, Lucena C, Herrera LJ, Yebra A, Bona AD, Perezc MM. Translucency thresholds for dental materials. Dent Mater 2018;34(8):1168-1174.
12. Jin J, Takahashi H, Iwasaki N. Effect of test method on flexural strength of recent dental. Dent Mater J 2004;23(4):490-6.
13. Ritter JE, Jakus K, Batakis A, Bandyopadhyay N. Apprisal of biaxial flexural strength testing. J Non-Cryst Solids 1980;38-39:419-424.
14. International Organization for Standardization, Technical Committee ISO/TC 106, Dentistry. Dentistry: Ceramic Materials (ISO 6872:2015). Switzerland: European Committee for Standardization; 2015.
15. Kaleli N, Sarac D, Kulunk S, Ozturk O. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: A three-dimensional finite element analysis study. J Prosthet Dent 2018;119(3):437-45.
16. Schmitter M, Mueller D, Rues S. Chipping behavior of all-ceramic crowns with zirconia framework and cad/cam manufactured veneer. J Dent 2012;40(2):154-62.
17. Pekkan G, Pekkan K, Bayindir BC, Ozcan M, Karasu B. Factors affecting the translucency of monolithic zirconia ceramics: A review from a materials science perspective. Dent Mater J 2020;39(1):1-8.
18. Terzioglu H, Yilmaz B, Yurdukoru B. The effect of different shades of specific luting agents and IPS empress ceramic thickness on overall color. Int J Periodontics Restorative Dent 2009;29(5):499-505.
19. Harianawala HH, Kheur MG, Apte SK, Kale BB, Sethi TS, Kheur SM. Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. J Adv Prosthodont 2014;6(6):456-61.
20. Kwon SJ, Lawson NC, McLaren EE, Nejat HA, Burgess JO. Comparison of the mechanical properties of translucent zirconia and lithium disilicate. J Prosthet Dent 2018;120(1):132-7.
21. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. J Dent Res 2018;97(2):140-7.
22. Carrabba M, Keeling AJ, Aziz A, et al. Translucent zirconia in the ceramic scenario for monolithic restorations: A flexural strength and translucency comparison test. J Dent 2017;60:70-6.
23. Manziuc M, Gasparik C, Negucioiu M, et al. Optical properties of translucent zirconia: A review of the literature. Eurobiotech J 2019;3(1):45-51.
24. Egen M, Braun L, Zentel R, et al. Artificial opals as effect pigments in clear-coating. Macromol Mater Eng 2004;289:158-63.
25. Willard A, Gabriel Chu TM. The science and application of IPS e.Max dental ceramic. Kaohsiung J Med Sci 2018;34(4):238-42.
26. Scientific documentation IPS e.Max cad. Available at "https://ivodent.hu/__docs/768_865d8476b1360c8ac461ae57f9c6b3c4.pdf". Accessed July 26, 2021.
27. El-Meliegy E, Van Noort R. Lithium Disilicate Glass Ceramics. In: El-Meliegy E, Van NR, eds. Glasses and glass ceramics for medical applications. New York: Springer Link; 2012:209-18.
28. Kohorst P, Borchers L, Strempel J, et al. Low-temperature degradation of different zirconia ceramics for dental applications. Acta Biomater 2012;8(3):1213-20.
29. Uwalaka CO, Karpukhina N, Cao X, Bissasu S, Wilson RM, Cattell MJ. Effect of sandblasting, etching and resin bonding on the flexural strength/bonding of novel glass-ceramics. Dent Mater 2018;34(10):1566-77.
30. Pardo NP, Araya PL, Pardo MP. Effect of different surface treatment on the bonds strength of a resin cement in zirconia frameworks. J Int Dent Med Res 2016;9(1):1-5.
31. Carlos EP, Geraldo AC, Simone K, Aline BF, Elimario VR, Sergio CD. Influence of the surface treatment on shear bond strength of coating ceramics of zirconia. J Int Dent Medical Res 2017;10(2):193-7.