Flexural Strength and Fracture Resistance of Leucite-Reinforced Glass Ceramic for Dental CAD/CAM

Meryem Hurbag*, Asude Dilek Nalbant and Emre Tokar

Department of Prosthodontics, Gazi University Faculty of Dentistry, Emek, Ankara, Turkey

Abstract: *Statement of the Problem:* Leucite-reinforced CAD/CAM ceramics are aesthetic restorative materials with a very close value of translucency, fluorescence and opalescence to natural teeth, however their flexural strength and fractural resistance values should be evaluated. The purpose of this systematic review was to analyze the fracture resistance and flexural strength values of leucite-reinforced CAD/CAM ceramic materials among the literatures published between 2008 and May 2018.

Materials and Methods: An electronic research for articles in English-language, published between 2008 and May 2018 was performed with the help of PubMed search engine. The keywords used were IPS Empress CAD, Rosetta BM, flexural strength, fracture resistance.

After applying the predetermined inclusion criteria; the definitive list of selected articles was suitable only for analyzing the flexural strength and fracture resistance values of leucite reinforced CAD/CAM ceramics. Literatures evaluating other ceramics and other criteria such as 'fatigue resistance' and 'optical properties' were excluded.

Results: The systematic application of inclusion criteria resulted in 18 literatures that analyzed the fractural resistance and flexural strength of leucite-reinforced CAD/CAM restorative material. 17 literatures conducted researches about IPS Empress CAD ceramic and 1 was about Rosetta BM ceramic, since it is a new ceramic.

Conclusion: For IPS Empress CAD restorative material, the literatures scanned indicated superior aesthetic properties however limited success rate at flexural strength and fractural resistance, especially when compared with IPS E.max CAD restorative material which is more recommended for posterior restorations. For Rosetta BM ceramic; only one literature was found; which reported that Rosetta BM ceramic showed better fracture and strength values when compared to IPS Empress CAD ceramic. However more investigations are needed to be done for both materials in order to develop leucite-reinforced CAD/CAM materials usage; especially in the posterior regions.

Keywords: IPS empress CAD, Rosetta BM, Flexural strength, Fracture resistance.

1. INTRODUCTION

In dentistry, ceramics are regularly used due to their superior aesthetic properties, durability, biological qualities and surface hardness, as restorative materials to restore lost or damaged teeth for more than 100 years as individual crowns, veneers, onlays, inlays, fixed partial dentures and implant restorations [1-4].

In the mid 1960s, with the presentation of aluminous porcelain by John McLean, there have been rapid improvements in their microstructure, durability, fabrication methods, translucency, abrasive effect on the antagonist teeth and etc. resulting in the production of many different products [5].

Having many different products available, clinicians face some difficulties in making decision of which ceramic material to use for particular indications [5]. Therefore classification systems of the ceramic materials are arranged in order to help and guide the clinicians. A classification system by Kelly and Bennetti [2] described ceramic materials according to their glass ingredient and divided into groups as; principally glassy materials, particle-filled glasses and polycrystalline ceramics which don't have any glass content.

In 2015, a new classification system according to the existence of some particular materials in ceramic restorative materials' structure was announced. According to this classification; ceramics are divided into 3 classes; glass matrix ceramics (inorganic non-metallic ceramic materials with a phase of glass), polycrystalline ceramics (inorganic non-metallic ceramic materials with no glass phase) and resin matrix ceramics (polymer matrices with mostly inorganic compounds and may contain porcelain, glasses, ceramics and glass ceramics).The glass matrix ceramics were then divided into feldspathic ceramics, synthetic ceramics and glass infiltrated ceramics. Polycrystalline ceramics are further divided into alumina, stabilised zirconia, zirconia toughened alumina and alumina toughened zirconia. Resin matrix ceramics are also subdivided into resin nano ceramic, glass ceramic in a resin interpenetrating matrix and zirconia-silica ceramic in a resin interpenetrating matrix according to their composition [5].

*Address correspondence to this author at the Department of Prosthodontics, Gazi University Faculty of Dentistry, Emek, Ankara, Turkey;
Tel: 00903122024193; Fax: 00903122239226
E-mail: emretokar@yahoo.com

E-ISSN: 2311-8695/18

IPS Empress ceramics belong to the glass matrix ceramics class. The IPS Empress system was firstly developed in Zurich, Switzerland in 1983, Ivoclar presented it to the profession in the year 1990 [6]. IPS Empress system is a leucite reinforced glass ceramic which satisfies the standards required from aesthetic restorations like inlays, onlays, veneers and crowns [7]. Main advantage of the system is the injection molding process which combines heat and pressure and brings leucite crystals together to reduce tensile stress and micro cracks formation in order to develop bending strength and fracture resistance. Combination of heat and pressure decreases the amount of ceramic shrinkage and improves the flexural strength [6-8].

IPS Empress feldspathic porcelain basically consists of silicone dioxide and aluminium oxide where the leucite crystals are added [7]. İn 1998, lithium disilicate and lithium ortophosphate crystals were added by reducing the glass matrix in order to improve the IPS Empress system. IPS Empress 2 system was developed. Fluorapatite based ceramics are added on the infrastructures made by Empress 2. İt was reported that this new type of porcelain has better hardness and density values [9, 10]. The strength values of IPS Empress I ranges from 95 to 180 Mpa and its fracture toughness is proximately 1.3 Mpa m ½, it is not recommended for fabrication of bridges. Glass ceramic which is reinforced with lithium disilicate has strength values approximately 340 -400 Mpa and fracture toughness 3.3 Mpa $m^{1/2}$, but this material needs to be veneered [11]. İn 2006 translucent lithium disilicate material IPS E-max Press replaced IPS Empress II material which gives permission to the fabrication of full-contour ceramic restorations [12].

There are 3 ways in all-ceramic manufacturing; conventional sintering techniques, fabrication by casting or pressure technique and direct milling techniques (CADCAM) [13]. During the fabrication of IPS Empress restoration, the framework is produced in a dental laboratory using the lost wax technique. The ingots of glass ceramic material are fixed into a pressing furnace and heated till 1180 °C (for IPS Empress 1) or till 920 °C (for IPS Empress 2), after they gain a viscous state at these high temperatures they are pressed in a mold to compose the ceramic restoration [11]. After the casting procedure, there are 2 ways of finishing the restoration. One is the shading technique where the restoration is first made in the neutral shade of the ingot, then a characterization pigment is added and glazed [6, 14]. The other procedure is the layering technique where the dentin part of the restoration is made by a dentin shade ingot and then the enamel layer is added [7, 15].

CADCAM system (Computer-aided design and computer-aided manufacturing) was firstly announced in the market in the mid 1980s. The CADCAM system uses machinable ceramic materials and allows the fabrication of full ceramic restorations in a short period of time compared to other conventional techniques. Since the time it was introduced, many improvements were made in the software and the hardware of the system [16].

In the year 2006, IPS Empress CAD materials were presented in the market for the production of inlays, onlays, anterior and posterior crowns. IPS Empress CAD ingots have a homogeneous distribution of leucite crystals. The crystals have a diameter of 1 to 5 µm and a crystal phase volume of 35 to 45%. Leucite is a result of surface crystallization. They don't require any additional manufacturing procedures; they can be finished/polished manually by the clinician or the technician [9, 17-19].

Leucite reinforced ceramic restorations show superior aesthetic properties; their translucency, fluorescence and opalescence values are very close to natural teeth. One disadvantage of IPS Empress restorations is their low mechanical strength which is a handicap for preparing bridge restorations especially in the posterior regions [6, 11].

Accordingly; aim of this literature review was to analyse the flexural strength and fracture resistance values of two leucite-reinforced CAD/CAM ceramics; IPS Empress CAD (Ivoclar Vivadent Schaan, Liechtentein) and Rosetta BM (HASS, Gangneung, Korea) among the literatures published between 2008 and may 2018.

2. MATERIALS AND METHODS

A literature search was conducted in May 2018 to classify the mechanical success of IPS-Empress CAD ceramic restorations among the studies that were published in the last 10 years, between 2008 and 2018 May. Only studies published in English and analyzed "Leucite-reinforced ceramic", "CAD/CAM", "fracture resistance", "flexural strength" keywords were included. The studies including other criteria were excluded from the study.

3. DISCUSSION

This literature review aimed to analyze the mechanical properties (fracture resistance and flexural strength) of leucite-reinforced glass ceramic for dental

Reference	Purpose of the Study	Ceramic Materials Tested	Mechanical (Fracture Resistance/Flexural Strength) Test Applied	Results
Vichi *et al.* [16]	to evaluate the flexural strength of CEREC CADCAM materials' and make comparison between the ISO standardized set up	Paradigm C, IPS Empress CAD LT, IPS Empress CAD Multi, Cerec Blocs, Cerec Blocs PC, Triluxe, Triluxe Forte, Mark II	Flexural strength: Universal testing machine, Three-point bending test	IPS Empress CAD ceramic's flexural strength values were greater than 100 Mpa and satisfied the standards stated by ISO
Keshvad *et al.* [20]	to assess the marginal gap, internal fit, and fracture load of mesioocclusal-distal (MOD) inlays fabricated by CADCAM system or hot pressing technique	IPS Empress and ProCAD	Fracture test: Universal testing machine (Z020, Zwick/Roell, Ulm, Germany)	No significant differences in the fracture load values or the internal fit values between the two ceramic systems
Asai *et al.* [21]	to compare the effect of overglazing and polishing processes on the compressive fracture strength of machinable ceramic materials	Vita Mark II, ProCAD/IPS Empress CAD,IPS e.max CAD	Fracture strength: Universal testing machine (EZ Test, Shimadzu, Kyoto, Japan)	Fracture load applied to IPS E.max CAD was significantly higher than ProCAD and IPS Empress CAD, Vita Mark II Overglazed and polished surfaces showed similar compressive fracture strengths irrespective of the ceramic material
Albero *et al.* [22]	to evaluate the mechanical properties of five CAD/CAM materials	Vıta Enamic, Lava Ultimate, Mark II, IPS E.max CAD and IPS Empress CAD	Flexural strength: Universal testing machine in a three point flexure (Instron 4411, Massachusetts)	IPS Empress CAD standed out as the least resistant material IPS E.max showed superior mechanical properties compared to other materials
Awada and Nathanson [23]	to assess the mechanical properties and margin line quality of polymer based CAD/CAM materials	Lava Ultimate, Cerasmart, IPS Empress CAD, Vita Block Mark II and Paradigm MZ100 block	Flexural strength: Universal Testing Machine (Instron 5566A;Instron Co) 3-point flexural test	Flexural strength and the resilience modulus of IPS Empress CAD and Vita Mark II was lower than Cerasmart and Lava Ultimate, Flexural modulus of IPS Empress CAD and Vıta Mark II was higher than Cerasmart and Lava Ultimate
Stawarczyk *et al.* [24]	to investigate the mechanical and optical properties of IPS Empress CAD and other restorative materials	(IPS e.max CAD, VİTA Enamic, Lava Ultimate, Cerasmart, Shofu Block and two CADCAM composites	Flexural strength: Universal testing machine(Zwick/ Roell 1445,Zeick,Ulm,Germany) 3-point flexural strength	Among the other tested materials IPS Empress CAD showed lower flexural strength and two-body wear values and a favourable discoloration value
Flury *et al.* [25]	to investigate the effect of surface roughness on the mechanical properties (surface hardness, elastic modulus and flexural strength) of two CAD/CAM ceramic materials	VITABLOCS Mark II (VMII) IPS Empress CAD	Surface hardness and Elastic Modulus: Hardness indentation device(Fischerscope HM2000, Helmut Fischer GmbH, Sindelfingen, Germany) Flexural strength: Zwick Z010 universal testing machine –three point bending test(Zwick GmbH & Co, Ulm, Germany)	As surface gets smoother the ceramic material, both Vitablocks Mark II and IPS Empress CAD ceramic material, showed better mechanical properties
Hamburger *et al.* [26]	to evaluate the failure risk of indirect and direct restorative materials	IPS e-max CAD, IPS Empress CAD, Clearfill AP-X(Kuraray), TetricEvo-Ceram(Ivoclar Vivadent)	Fracture resistance: Universal testing device, unaxially loaded until fracture(MTS,858 Mini Bionix II)	Positive correlation was found between the thickness of the layer and the compressive strength values of the restorative materials tested IPS Empress CAD showed significantly worse results than other materials, especially IPS e-max CAD

Ozcan and Sahin [27]	to measure the fracture strength of all-ceramic core materials on posts produced from zirconia	Three groups: one-piece zirconia post-core, IPS Empress CAD core luted to zirconia post, IPS Empress pressed to zirconia post	Fracture strength: Compressive load at 45° to the long axis of the tooth, at a crosshead speed of 1 mm/min, 4 mm from the incisal edge	No significant statistical differences between the groups tested
Lin *et al.* [28]	to correlate the effect of veneering porcelain and the core fabrication technique (pressed or CAD/CAM) for the leucite and lithium disilicate reinforced ceramics, and the effect of veneering technique for zirconia ceramics.	Five ceramic core materials: IPS Empress Esthetic, IPS Empress CAD, IPS e.max Press, IPS e.max CAD, IPS e.maxZirCAD Three veneering materials: IPS Empress Esthetic Veneer, IPS e.max Ceram, IPS e.max Zir Press	Biaxial flexural strength: Universal testing machine (Instron, Norwood, MA)	IPS Empress ceramics, no matter of fabrication technique and the material thickness, showed lower flexural strength than IPS e.max ceramics.
Skouridou *et al.* [29]	to evaluate the fracture strength of traditionally, minimally and occlusal veneer prepared crowns	IPS Empress CAD	Fracture strength: -Masticatory simulator (TCML, -Chewing simulator, EGO, Regensburg, Germany) -Fracture testing machine (Zwick,1446s,Ulm,Germany)	All groups demonstrated crack formation and further studies are needed to be performed
Nossair *et al.* [30]	to compare the fracture resistance of cemented and Cad-on IPS Empress CAD veneers on zirconia implant custom abutments	CAD/CAM zirconia implant abutments IPS Empress CAD	Fracture strength test: Universal testing machine (Instron 6022; Instron Limited, High Wycombe, UK)	Cemented Cad-on restorations demonstrated higher fracture resistance than fused Cad-on restorations
Oz and Bolay [31]	to compare the marginal integrity and fracture resistance of inlays produced by CAD/CAM system or heat pressed technique	IPS e-max CAD, Lava Ultimate, IPS Empress CAD, IPS Empress Aesthetic ingots	Fracture strength: Universal testing machine (Lloyd Instruments LR 50K, AMETEK GmbH, Meerbusch, Germany)	No significant difference in fracture strength values between the inlays produced from CEREC Omnicam and heat-pressed technique. İnlays produced by CAD/CAM system demonstrated better marginal adaptation.
Sagsoz *et al.* [4]	to assess the fracture strength and surface microhardness of CAD/CAM materials	Feldspathic ceramic, IPS Empress CAD, Lava Ultimate, Vıta Enamic, IPS e-max CAD	Fracture strength: Universal test device; Shimadzu AG-IS1000 (Shimadzu Corporation, Kyoto, Japan)	Fracture resistance of IPSe.max CAD was significantly higher than the rest of the materials tested. IPS Empress CAD owned the lowest fracture strength value
Stona *et al.* [32]	to assess the fracture resistance of three types of ceramic crowns luted on solid abutments	IPS Empress CAD,CEREC VITABLOCKS Mark II and IPS e.max CAD	Fracture resistance: Universal testing machine(DL-2000,EMIC)	IPS Empress CAD and IPS e.max CAD demonstrated better fracture resistance when compared with CEREC VITABLOCS Mark II
Liu *et al.* [33]	to assess the influence of cavity design(non-proximal box and proximal box design) and restorative material on the fracture resistance of inlay restorations	Composite resin(MZ100,3M ESPE) IPS Empress CAD	Fracture resistance: MTS machine(810 Material Testing System, MTS, USA)	No significant differences between the same material, different cavity design. Composite resin showed better fracture resistance than IPS Empress CAD restorations
Zierden *et al.* [34]	to study the fracture and wear strength of two ceramic resins and two conventional ceramics	Lava Ultimate, Vita Enamic, IPS Empress CAD, Celtra Duo	Fracture strength: Loaded until restorations fractured(0.5 mm/minute feed; Zwick 1454)	IPS Empress CAD showed the least fracture strength before and after cyclic loading

Byeon and Song [35]	to study the mechanical and microstructural properties of leucite-reinforced glass ceramic materials	IPS Empress CAD and Rosetta BM	Flexural strength: Loaded with piston-on-three-ball method at a crosshead speed of 0.5 mm/min Fracture toughness: Indentation fracture method	Rosetta BM showed superior fracture and toughness values than IPS Empress CAD restorative material

CAD/CAM through the literatures published between 2008 and May 2018.

Vichi *et al.* [16] conducted a study using a 3 point bending test with a Universal Testing Machine to evaluate the flexural strength of CEREC CADCAM materials' and make comparison between the ISO standardized set up; since this standard was announced later than the production of these ceramic materials. After the test they reported that the all ceramic materials', including IPS Empress CAD ceramic, flexural strength values were found to be greater than 100 Mpa, which satisfied the standards stated by ISO. They also reported that IPS Empress CAD restorative material showed statistically higher flexural strength when compared to other materials tested in the study. A similar study was carried out by Albero *et al*. [22] to evaluate the mechanical properties of Vita Enamic, Lava Ultimate, Mark II, IPS e.max CAD and IPS Empress CAD materials with a Universal Testing Machine, three point bending test. They stated that IPS Empress CAD ceramic material was the least resistance material to flexure. Also, Stawarczyk *et al.* [24] studied with a Universal Testing Machine(three point bending test) to investigate the mechanical properties of IPS Empress CAD and other restorative materials (IPS e.max CAD, VİTA Enamic, Lava Ultimate, Cerasmart, Shofu Block and two CADCAM composites).They represented that among the other materials IPS Empress CAD showed lower flexural strength and two-body wear values. İn another study evaluated by Awada and Nathanson [23], the mechanical properties(Universal Testing Machine, three point bending test) and margin line quality of polymer based CADCAM materials were aimed to be measured (Lava Ultimate, Cerasmart, IPS Empress CAD, Vita Block Mark II and Paradigm MZ100 block), and they reported that the flexural modulus of IPS Empress CAD restorative material was higher than the other materials, whereas its flexural strength and the resilience modulus was lower.

A research was presented by Asai *et al.* [21] in order to compare the effect of overglazing and polishing processes on the compressive fracture strength of machinable ceramic materials (Vita Mark II, ProCAD and IPS Empress CAD, IPS e.max CAD). They concluded that the fracture load applied to IPS e.max CAD was significantly higher than ProCAD and IPS Empress CAD, whereas the fracture load was the lowest at Vita Mark II and no significant fracture strength value changes were observed between the overglazed and polished groups of IPS Empress CAD material. They also stated that the overglazed and the polished surfaces showed close values of compressive fracture strengths irrespective of the ceramic restoration used.

Flury *et al*. [25] carried out a research to investigate the effect of surface roughness on the mechanical properties (surface hardness, elastic modulus and flexural strength) of IPS Empress CAD and VITABLOCS Mark II (VMII) ceramics. At the end of the research they concluded that as the surface got smoother both of the ceramic materials showed better mechanical properties (surface hardness, elastic modulus, flexural strength).

An *in vitro* study was performed by Hamburger *et al.* [26] evaluate the failure risk of IPS Empress CAD,IPS e.max CAD and two composite materials with different layer thicknesses. They stated that a positive correlation was found between the thickness of the layer and the compressive strength values, however IPS Empress CAD showed the worst results among the other materials.

Ozcan and Sahin [27] conducted an *in vitro* study was done to measure the fracture strength by applying compressive load at 45° to the long axis of the tooth, at a crosshead speed of 1 mm/min, 4 mm from the incisal edge of all-ceramic core materials on posts produced from zirconia. Three groups were composed and loads were applied (G1:one-piece zirconia post-core, G2: IPS Empress CAD core luted to zirconia post, G3:IPS Empress pressed to zirconia post). At the end it was reported that no significant statistical differences were found between the fracture strength values of the groups tested.

A study was carried out by Lin *et al*. [28] to correlate the effect of veneering porcelain and the core fabrication technique (pressed or CAD/CAM) for the leucite and lithium disilicate reinforced ceramics, and also the effect of veneering technique for zirconia ceramics on the Weibull modulus and biaxial flexural

strength. As a result they stated that the IPS Empress ceramics, no matter of fabrication technique (heat pressed or CAD/CAM) and the material thicknesses, showed lower flexural strength than IPS e.max ceramics.

A study was presented by Skouridou *et al*. [29] to evaluate the fracture strength of traditionally prepared crowns, minimally prepared crowns and occlusal veneer prepared crowns produced from IPS Empress CAD restorative material. At the end of the study it was reported that no significant differences were found between the groups, all groups demonstrated crack formation, and further studies should be performed for more precise results.

Nossair *et al.* [30] conducted a research to compare the fracture resistance of cemented and Cad-on IPS Empress CAD veneers on zirconia implant custom abutments. It was stated that cemented Cad-on restorations demonstrated higher fracture resistance than fused Cad-on restorations.

A study was carried out by Oz *et al.* [31] to compare the marginal integrity and fracture resistance of inlays produced by CAD/CAM system or heat pressed technique. As a result they presented that; no significant difference in fracture strength values was found between the inlays produced from CEREC Omnicam and heat-pressed technique.

Sagsoz *et al*. [4] conducted an *in vitro* research to assess the fracture strength and surface micro-hardness of IPS Empress CAD, Lava Ultimate, Vita Enamic and IPS e.max CAD. They represented that the fracture resistance of IPS e.max CAD was significantly higher than the rest of the materials tested, IPS Empress CAD owned the lowest fracture strength value.

A study was performed by Stona *et al*. [32] to assess the fracture resistance of IPS Empress CAD,CEREC VITABLOCKS Mark II and IPS e.max CAD crowns luted on solid abutments. They concluded that all of the materials tested showed sufficient resistance to normal chewing forces however IPS Empress CAD and IPS e.max CAD demonstrated better fracture resistance compared with CEREC VITABLOCS Mark II.

Liu *et al*. [33] carried out a research to assess the influence of cavity design and restorative material on fracture resistance of inlay restorations. At the end of the research they reported that IPS Empress CAD restorative material showed worse fracture resistance values than the other materials tested.

Zierden *et al*. [34] investigated research to observe the wear and fracture strength of Lava Ultimate (3M ESPE), Vita Enamic (Vita Zahnfabrikand), IPS Empress CAD (Ivoclar Vivadent) and Celtra Duo (Dentsply / DeguDent GmbH) restorative materials. They reported that IPS Empress CAD restorative materials showed lower fracture resistance values than all the other materials tested.

Byeon and Sond [35] conducted a study in order to evaluate the mechanical properties and microstructure of leucite-reinforced glass CAD/CAM ceramics; IPS Empress CAD and Rosetta BM. They reported that Rosetta BM ceramic material represented better strength and fracture toughness values than IPS Empress CAD ceramic material, and further studies should be done for more accurate results.

CONCLUSION

Within the limitations of this systematic review, it can be concluded that the leucite-reinforced ceramic materials demonstrate superior aesthetic properties, satisfying both the patient and the dentist. However their mechanical properties are weak and not resistant enough to overcome mechanical forces. The use of leucite-reinforced CAD/CAM ceramic materials are indicated mainly as inlays, onlays, veneers, crowns and not recommended as bridges; especially in the posterior regions.

REFERENCES

[1] Toksavul S and Toman M. A short-term clinical evaluation of IPS Empress 2 crowns. Int J Prosthodont 2007; 20(2): 168-172.

[2] Kelly J R, Nishimura I and Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent 1996; 75(1): 18-32. https://doi.org/10.1016/S0022-3913(96)90413-8

[3] Spohr AM, Sobrinho LC, Consani S, Sinhoreti MAC and Knowles JC. Influence of surface conditions and silane agent on the bond of resin to IPS Empress 2 ceramic.Int J Prosthodont 2003; 16(3):277-282.

[4] Sagsoz O, Yıldız M, Hojjat Ghahramanzadeh ASL and Alsaran A. *In vitro* fracture strength and hardness of different computer-aided design/computer-aided manufacturing inlays. Niger J Clin Pract 2018; 21: 380-7.

[5] Gracis S. A New Classification System for All-Ceramic and Ceramic-like Restorative Materials. Int J Prosthodont 2015; 28(3): 227-235. https://doi.org/10.11607/ijp.4244

[6] Dong JK, Luthy H, Wohlwend

[7] A and Schärer P. Heat-pressed ceramics: technology and strength. Int J Prosthodont 1992; 5(1): 9-16.

[8] El-Mowafy O and Brochu JF. Longevity and clinical performance of IPS-Empress ceramic restorations-a literature review. J Can Dent Assoc 2002; 68(4): 233-237.

[9] Ohyama T, Yoshinari M and Oda Y. Effects of cyclic loading on the strength of all ceramic materials. Int J Prosthodont

1999; 12(1): 28-37.

[10] Sorensen JA, Cruz M, Mito WT, Raffeiner O, Meredith HR, and Foser HP. A clinical investigation on three-unit fixed partial dentures fabricated with a lithium disilicate glass-ceramic. Pr Periodontics Aesthet Dent 1998; 11(1): 95-106.

[11] Marquardt P and Strub JR. Survival rates of IPS empress 2 all-ceramic crowns and fixed partial dentures: results of a 5-year prospective clinical study. Quintessence Int 2006; 37(4): 253-259.

[12] Höland W, Schweiger M, Frank M and Rheinberger V. A comparison of the microstructure and properties of the IPS Empress®2 and the IPS Empress® glass-ceramics. J Biomed Mater Res 2000; 53(4): 297-303. https://doi.org/10.1002/1097-4636(2000)53:4<297::AID-JBM3>3.0.CO;2-G

[13] Heintze SD and Rousson V. Fracture rates of IPS Empress all-ceramic crowns-a systematic review. Int J Prosthodont 2010; 23(2): 129-33.

[14] Gemalmaz D and Ergin S. Clinical evaluation of all-ceramic crowns. J Prosthet Dent 2002; 87(2): 189-196. https://doi.org/10.1067/mpr.2002.120653

[15] Luthy H and Dong J. Effects of veneering and glazing on the strength of heat-pressed ceramics. Schweiz Monatsschr Zahnmed 1993; 103(10): 1257-1260.

[16] Frankenberger R, Petschelt A and Krämer N. Leucite-reinforced glass ceramic inlays and onlays after six years: clinical behavior Oper Dent 2000; 25(6): 459-65.

[17] Vichi A, Sedda M, Del Siena F, Louca C and Ferrari M. Flexural resistance of Cerec CAD / CAM system ceramic blocks. Part 1 : Chairside materials. Am J Dent 2013; 26(5): 255-9.

[18] Sorensen JA, Choi C, Fanuscu MI and Mito WT. IPS Empress crown system: three-year clinical trial results. J Calif Dent Assoc 1998; 26(2): 130-6.

[19] Taskonak B and Sertgöz A. Two-year clinical evaluation of lithia-disilicate-based all-ceramic crowns and fixed partial dentures. Dent Mater 2006; 22(11): 1008-1013. https://doi.org/10.1016/j.dental.2005.11.028

[20] Tinschert J, Natt G, Mautsch W, Augthun M and Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a laboratory study. Int J Prosthodont 2015; 14(3): 231-238.

[21] Keshvad A, Hooshmand T and Asefzadeh F. Marginal Gap, Internal Fit and Fracture Load of Leucite-Reinforced Ceramic Inlays Fabricated by CEREC inLab and Hot-Pressed Techniques. J Prosthodont 2011; 20(7): 535-540. https://doi.org/10.1111/j.1532-849X.2011.00745.x

[22] Asai T, Kazama R, Fukushima M and Okiji T. Effect of overglazed and polished surface finishes on the compressive fracture strength of machinable ceramic materials. Dent Mater J 2010; 29(6): 661-7. https://doi.org/10.4012/dmj.2010-029

[23] Albero A, Pascual A, Camps I and Grau-Benitez M. Comparative characterization of a novel cad-cam. J Clin Exp Dent 2015; 7(4): 495-500. https://doi.org/10.4317/jced.52521

[24] Awada A and Nathanson D. Mechanical properties of resin-ceramic CAD / CAM restorative materials. J Prosthet Dent 2014; 114(4): 587-593. https://doi.org/10.1016/j.prosdent.2015.04.016

[25] Stawarczyk B, Liebermann A, Eichberger M, Guth JF. Evaluation of mechanical and optical behavior of current esthetic dental restorative CAD / CAM composites. J Mech Behav Biomed Mater 2016; 55: 1-11. https://doi.org/10.1016/j.jmbbm.2015.10.004

[26] Flury S, Peutzfeldt A and Lussi A. Influence of Surface Roughness on Mechanical Properties of Two Computer-aided Design/Computer-aided Manufacturing (CAD/CAM) Ceramic Materials. Oper Dent 2012; 37(6): 617-62. https://doi.org/10.2341/11-391-L

[27] Hamburger JT, Opdam NJ, Bronkhorst EM and Huysmans MC. Indirect restorations for severe tooth wear: Fracture risk and layer thickness. J Dent 2013; 42(4): 413-418. https://doi.org/10.1016/j.jdent.2013.10.003

[28] Ozcan N and Sahin E. *In vitro* evaluation of the fracture strength of all - ceramic core materials on zirconium posts. Eur J Dent 2013; 7(4): 455-460. https://doi.org/10.4103/1305-7456.120671

[29] Lin W, Ercoli C, Feng C and Morton D. The Effect of Core Material, Veneering Porcelain, and Fabrication Technique on the Biaxial Flexural Strength and Weibull Analysis of Selected Dental Ceramics. J Prosthodont 2012; 21(5): 353-62. https://doi.org/10.1111/j.1532-849X.2012.00845.x

[30] Skouridou N, Pollington S, Rosentritt M, Tsitrou E. Fracture strength of minimally prepared all-ceramic CEREC crowns after simulating 5 years of service. Dent Mater 2013; 29(6): 70-77. https://doi.org/10.1016/j.dental.2013.03.019

[31] Nossair SA, Aboushelib MN and Morsi TS. Fracture and fatigue resistance of cemented versus fused CAD-on veneers over customized zirconia implant abutments. J Prosthodont 2015; 24(7): 543-548. https://doi.org/10.1111/jopr.12253

[32] Oz FD and Bolay S. Comparative evaluation of marginal adaptation and fracture strength of different ceramic ınlays produced by CEREC Omnicam and Heat-Pressed Technique. Int J Dent 2018. https://doi.org/10.1155/2018/5152703

[33] Stona D, Burnett LH Jr, Mota EG and Spohr AM. Fracture resistance of computer-aided design and computer-aided manufacturing ceramic crowns cemented on solid abutments. J Am Dent Assoc 2018; 146(7): 501-507. https://doi.org/10.1016/j.adaj.2015.02.012

[34] Liu X, Fok A and Li H. Influence of restorative material and proximal cavity design on the fracture resistance of MOD inlay restoration. Dent Mater 2013; 30(3): 327-333. https://doi.org/10.1016/j.dental.2013.12.006

[35] Zierden K, Acar J, Rehmann P and Wöstmann B. Wear and Fracture Strength of New Ceramic Resins for Chairside Milling. Int J Prosthdont 2018; 31(1): 74-77. https://doi.org/10.11607/ijp.5492

[36] Byeon SM, Song JJ. Mechanical properties and microstructure of the leucite-reinforced glass ceramics for dental CAD/CAM. J Dent Hyg Sci 2018; 18(1): 42-49. https://doi.org/10.17135/jdhs.2018.18.1.42

Received on 18-09-2018 Accepted on 02-10-2018 Published on 31-12-2018

DOI: https://doi.org/10.12974/2311-8695.2018.06.6