Evaluate the Flexural Strength of Zirconia Fixed Partial Denture with Different Connector Designs

[1]Noor A. Abdul-Kareem B.Sc. and [2]Ihab N. Yassen, MSc.
[1, 2] Department of Prosthetic Dental Technology, College of Health and Medical Technology, Middle Technical University, Baghdad, Iraq
Corresponding author: Ihab Nafea Yassen
E-mail address: assist.prof.ihab@gmail.com

Received October 22, 2020.
Accepted for publication in December 06, 2020.
Published December 17, 2020.

Abstract

Background All-ceramic Fixed Partial Denture (FPD) restorations consisting of abutments, pontic, and connectors to link those parts together. Significantly, inappropriate connector shape reduces the restoration's strength and makes it susceptible to fracture and affecting the biological health conditions. **Objectives** The purpose of present in vitro study is to evaluate the flexural strength of all-ceramic FPD made from Yttrium-stabilized zirconium oxide (Y-TZP) IPS e.Max ZirCAD, (Ivoclar Vivadent) with different connector designs. **Materials and Methods** the specimens were designed into a bar shape with the help of a special 3D designing program (Sketchup, 3D design software). The connector of the specimens designed with two different radii of curvature designs (Sharp of 0.3mm and Round of 0.6 mm); then, the workpiece order was transferred to the CAM milling machine. After that, the specimens were sintered according to the manufacturer's instruction at (1500 ºC) for 6h. A universal testing machine was used for testing the flexural strength of zirconia specimens with 3 points flexural strength test with a crosshead speed of (0.5 mm/min). Data analyzed via One-way ANOVA and LSD tests performed at a significant P-value of ($p \leq 0.05$). **Results** After comparing results, a highly significant difference was noticed between the control group (with no constriction) and both sharp and round groups. While there was a non-significant difference between that of sharp and round radius of curvature groups. **Conclusion** Changing the connector design had a non-significant effect on the flexural strength of the (IPS e.max ZirCAD) FPD restoration.

Keywords: CAD/CAM technology; dental Materials; fixed partial denture; flexural strength; zirconia dental material

Introduction

Many different materials are used for the construction of FPDs with 3 units or more. Porcelain fused to metal is still known as the standard materials used. It was found that the survival rate is about 94% over 5 years. However, for esthetical reasons other optional materials are available, such as all-ceramic materials which include veneered zirconia, monolithic zirconia, monolithic lithium disilicate, and glass-infiltrated alumina (Heintze et al, 2018). Recently, there is an obvious flourish interest in the ceramic materials and systems for their unchallenged benefits such as the acceptable optical properties, good resistance to fracture to the intraoral functional load, and their bonding durability to the prepared tooth surface (Clausen et al, 2010; Kang et al, 2013). On the other hand, the fabrication simplicity of ceramic materials had become another reason, as the last 10 years had seen the rapid growth of new technologies along with the revolution of dental restorative materials such as computer-aided design/computer-aided manufacturing (CAD/CAM), laser sintering and 3D printing. These advanced technologies have had improved accuracy and reduced production time (Attia and Kern, 2004; Nassef et al, 2014; Zarone et al, 2016). The restorative dentistry's attention has widely grown towards high strength zirconia material in the past decade (Fischer et al, 2003; Kypraiou et al, 2012; Malkondu et al, 2016; Zhang and Lawn, 2018). Zirconia is a highly dense polycrystalline metal oxide ceramic block which has excellent mechanical properties than other ceramic materials due to their flexural strength (900-1200 MPa) and fractures toughness (9-10 MPa·m1/2) (Rismanchian et al, 2014). Thus, it can tolerate heavy load-bearing areas, high occlusal forces, and functional movements when it is fabricated as single crowns or as a fixed partial denture (Kermanshah et al, 2012, Saran-Babu et al, 2019, Sulaiman, 2020). Moreover, it offers many favorable properties such as higher bending strength than conventional ceramic materials (Ogino et al, 2016), but the opacity is considered as a serious matter of esthetic (Scherrer et al, 2017). However, despite the high mechanical properties of Y-TZP-based restorations, clinical failures still occur due to insufficient thickness of the framework and overloaded bruxism, and this mostly occurs at the connector area of FDPs (Oh et al, 2002; Hamza et al, 2016). Altering the connector design is an important issue for the restoration success (Rezaei et al, 2011); if the connector is large it could result in esthetical and hygienic problems. However, the greater the connector designed, is the strongest (Murase et al, 2014; Akbarzadeh, 2019). The connector›s shape is considered an important factor for FPD success. The load-bearing capacity is highly dependent on the radius of curvature at the gingival embrasure, during loading a small embrasure radii FPDs are subjected to high-stress concentrations compared to the FPDs with large embrasure radii (Bahat et al, 2009). Therefore, this study is aimed to investigate the effect of changing the connector design (radius of curvature), on the flexural strength of all-ceramic (Zir-CAD) FPD fabricated using CAD/CAM technology.

Materials and Methods

Specimens description

Bar-like rectangular shape specimens were made from IPS e-max ZirCAD blank (Ivoclar digital, Germany), (LOT No. X08278). The specimens were designed to resemble a 3 units FPD, based on the study of (Plengsombut et al, 2009; Hamza et al, 2016). The dimensions of the specimens were (30mm length × 4mm height × 4mm width), Figure (1). Each bar specimen is having two parts with a constriction simulating two connectors and determining a pontic in the center with a length of (10mm). The connector had a circular diameter with a (7mm2) cross-sectional area. Those connectors were designed with two different shapes; one was a round shape (0.6mm radius of curvature), and the other sharp shape (0.3mm radius of curvature), Figure (2) (Plengsombut et al, 2009, Hamza et al, 2016).

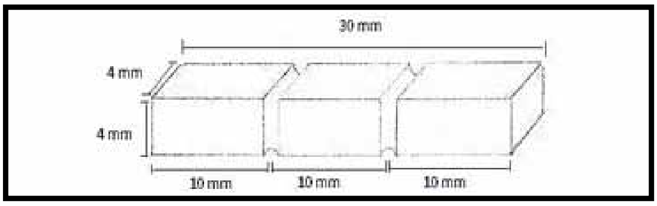
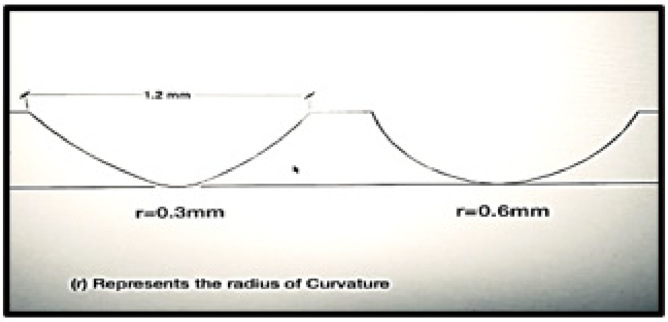


Figure (1): Specimens description.



Figure(2): Connector design.

Specimens design

The specimens were designed with a special 3D design software program (Sketchup 3D design software, v 2016), the design was produced in the form of an STL file (Stereo-litheography) in which the CAD/CAM system can understand. The specimen's drawings were converted into the 3D design, ready for milling with CAD/CAM machine.

Specimens grouping

21 bar shape specimens were divided into 3 groups according to the connector design. The first group representing specimens with no constriction served as a control group. The second group had a Round connector design (R) with (0.6mm radius of curvature) and the third group had a Sharp connector design(S) with (0.3mm radius of curvature).

Specimens fabrication

Partially sintered zirconia IPS e.Max ZirCAD, Ivoclar Digital blank (Yttrium-stabilized zirconium oxide for CAD/CAM technology) was used for the fabrication of specimens. The zirconia blank was with low translucency (LT) and (A2) shade, the diameter was (98.5mm2) and (14mm height).

Entering STL files to CAD system

A new workpiece was entered into the CAD software by determining the material's blank type which was Zirconium Oxide, followed by blank information such as dimension and serial number. After that, the specimens STL files were inserted into the program, and the milling type was determined as a full anatomical milling option. The next step was adjusting the virtual specimens in the correct positions till they fit and fill the size of the zirconia blank. After that, place the supporting bars on the sides of the specimens to hold them within the blank during the milling process. The specimens were designed to actual sizes with no enlargement, as The CAD/CAM system used was able to enlarge the zirconia specimens with optimal size to compensate for the shrinkage after sintering.

Transfer the workpiece to CAM system

The workpiece order was transferred to the CAM machine. zirconia blank was attached to the dry milling machine of 5 axis milling device (vfn camfacture AG, Lettenstabe 10-DE-72119 Ammerbuch, K5 Impression, 88 Mill-Five S, Germany, 2016), giving a possibility for milling the complicated geometries with subsections and fine details (Beuer et al, 2008; Yau et al, 2016).

Milling process

10 specimens were produced by each ZirCAD blank. The milling was started by cutting the outline of the specimens, then, the details of the connector's designs were milled at both ends of the bar by (10mm) distance between them. The diamond-coated cutter tools were changed from a larger size to the finest and smallest according to their function to produce the required design and details accurately (Hamza et al, 2016).

Detaching, cleaning and sintering

After milling, the specimens were detached carefully from the ZirCAD blank frame by using a handpiece device (Marathon-3dental handpiece, Korea) with a diamond disc, for cutting the supporting bars (IvoclarVivadent, 2019). The specimens were cleaned carefully with a soft brush to remove any zirconium oxide traces left on the specimens. The specimens were sintered according to the manufacturer's instructions at (1500ºC) for 6 hours with a ceramic furnace (Zubler Gerätebau GmbH, Germany). Normally, the zirconia specimens' dimensions were shrunk about 20-30% after sintering (Ahmed et al, 2020). Then, the entire bar access parts were removed by using a handpiece device with light pressure and low speed. It was possible to remove them immediately after detaching the specimens from the blank's frame but, non-sintered zirconium oxide specimens are susceptible to an unexpected defect that may occur during the working procedure (IvoclarVivadent, 2019). The dimensions of the specimens were checked and measured with an electronic caliper for the verification of their accuracy and to make sure that they were ready for flexural strength testing.

Three point flexural strength test of the zirconia specimens

The universal testing machine (LARYEE, 50kn, China, 2012) was used for testing the 3 points flexural strength of the specimens. The center of the pontic and abutment was marked accurately, and then the specimens were placed on the testing jig. A vertical loading force was applied by a steal rounded chisel with a diameter of (2mm) and the crosshead speed was (0.5mm per minute) at the center of the pontic and the connectors were supported around the center of the loading point (Hamza et al, 2016). The flexural strength was recorded with Mega Pascal (MPa) automatically by the testing machine computer software. The following formula of 3 points flexural strength test used was (Kopeliovich, 2012).

σ = 3FL / 2wd2

When F means the maximum force applied, L is the length of the specimen, w is the width of the specimen and d is the depth of the specimen.

Statistical analyses

Data analyzed using One-way ANOVA and LSD tests with a significant p-value of ($p \leq 0.05$).

Results

Table (1), (2), and figure (3) showed the results of flexural strength of ZirCAD specimens with different radius of curvatures. After comparing the results of flexural strength, a highly significant difference was noticed in the flexural strength between the control groups and both Round and Sharp connector design groups according to both ANOVA and LSD test ($p \leq 0.01$). While there was a non-significant difference between sharp and round connector design groups according to the LSD test.

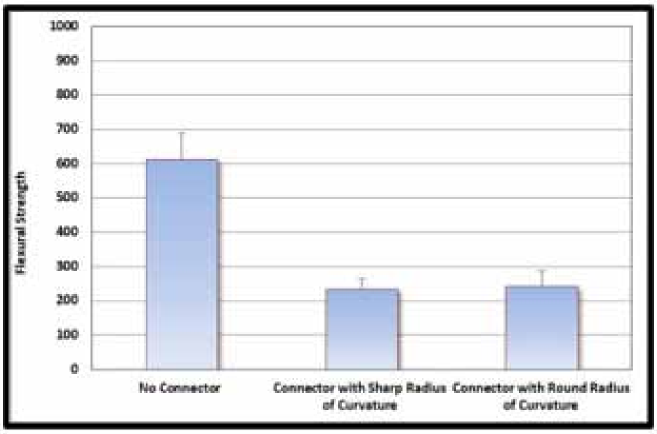


Figure (3): Bar-Chart showing the mean value of the 3 points flexural strength according to connector's radius of curvature (design).

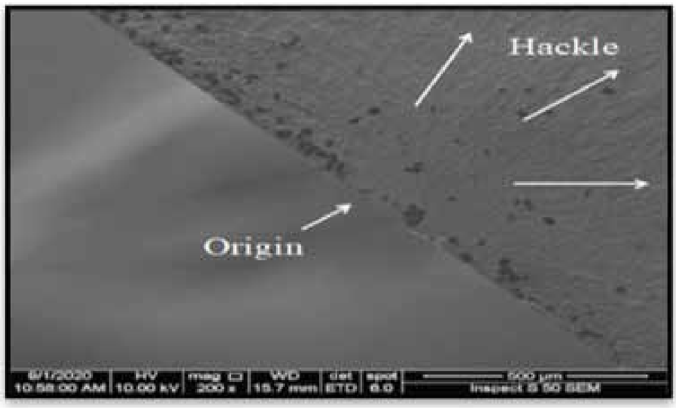


Figure (4): SEM demonstrating the stress origin and hackle radiations in the fracture surface of zirconia specimen (magnification, ×200).

Table (1): ANOVA test comparing the flexural strength according to connector's radius of curvature.

Grouping (I)	Grouping (J)	Mean Difference (I-J)	Sig.
No Connector	Connector with Sharp Radius of Curvature	377.857*	.000 (H.S.)
	Connector with Round Radius of Curvature	371.429*	.000 (H.S.)
Connector with Sharp Radius of Curvature	No Connector	-377.857*	.000 (H.S.)
	Connector with Round Radius of Curvature	-6.429-	.826 (N.S.)
Connector with Round Radius of Curvature	No Connector	-371.429*	.000 (H.S.)
	Connector with Sharp Radius of Curvature	6.429	.826 (N.S.)

Table (2): LSD test for multiple comparison of the flexural strength according to connector's radius of curvature.

Test	ANOVA	Sum of Squares	df	Mean Square	F-test	*p*-value
Flexural Strength	Between Groups	655145.238	2	327572.619	112.465	.000 (H.S.)
	Within Groups	52427.714	18	2912.651		
	Total	707572.952	20			

Discussion

Generally, all fixed prostheses are subjecting to compressive and tensile forces during function, and the area of the fracture risk is usually the connector area. When the force is applied directly to the FPD it will be under flexural-compressive loading occlusally with a concentration of tensile stress gingivally. Therefore, the design of the connector's area can be altered to improve the ability to withstand the loading forces (SaranBabu et al, 2019). The design of the specimens used in this study was similar to the design used by (Plengsombut et al, 2009) and (Hamza et al, 2016) according to the standardization of ceramic flexural strength test, including the use of bar-shaped specimens with two constrictions on either side representing the connectors with two different designs (sharp of 0.3mm and round of 0.6mm).

This study concluded that there was no significant difference between the group of the connector with a round radius of curvature (0.6mm) and the group of the connector with a sharp radius of curvature (0.3mm), suggesting that these results can be due to the stress distribution pattern, as (Oh et al, 2002) concluded. The material thickness at the proximal area helps to distribute stress, it is important for stress magnitude (Miura et al, 2017). Also, the zirconia material can dissipate the stress (Lakshmi et al, 2015). Therefore, fracture lines and stress were diffused in a larger area, resulting in uniform stress distribution and increased fracture strength (Kermanshah et al, 2012).

The sharp connector design acted as a macroscopic flaw (Oh et al, 2002) and it doesn't affect the stress concentration directly, but the microscopic scratches and sharp defects are the main reason for the initiation of crack sites (Kypraiou et al, 2012). The stress distribution depends on the fabrication technique and treatment of the framework, and as it is already known that the CAD/CAM is responsible for the most surface flaws, damages, and microcracks within the framework during the process of milling (Kypraiou et al, 2012; Ogino et al, 2016; SaranBabu et al, 2019), this is more significant especially in the ceramic materials which are brittle and containing various sizes and orientations of cracks and flaws, (Rezaei et al, 2011).

The results of this study were disagreed with (Hamza et al, 2016) in which their studies showed a significant difference between the sharp and round radius of curvature of all zirconia FPDs. concluded that the stress concentration decreased in connectors with a broad curvature compared to the connectors with narrow curvature (Nassef et al, 2014; Rismanchian et al, 2014; SaranBabu et al, 2019). On the other hand, Those results were agreed with (SaranBabu et al, 2019) in which their study found that there was no significant difference between sharp (0.25mm) and round (0.45mm) gingival radius of curvature at the stress distribution. And also agreed with (Akbarzadeh, 2019) who found that there was no significant difference in failure load of the group with (12 mm2) cross-sectional area made with a different embrasure design.

The current study didn't show a significant negative effect in the sharp connector design compared to the round connector design, this can be due to the transformation-toughening property of ZirCAD material, which gave it the ability to withstand the catastrophic force and also making it less affected by the sharp connector milling procedure (Plengsombut et al, 2009).

The fracture pattern of all specimens with Sharp connector design was less angulated toward the pontic area than specimens with Round connector design; this was agreed with (Fischer et al, 2003; Attia and Kern, 2004; Clausen et al, 2010; Hamza et al, 2016).

They found that the stress level decreased with smoother and less angled connectors. Thus, it can be possible to explain the different fracture directions in each connector design in the current study. The Scanning Electron Microscope (SEM) demonstrated a brittle smooth fracture surface, without significant plastic deformation prior to failure (Hamza et al, 2016).

The critical flaws and fine hackle radiating outward perpendicularly to the tensile stress representing the failure origin. Thus, the tensile stress direction causing the fracture can be identified (Scherrer et al, 2017). Fracture occurred in an area of high stress concentration. When the stress increased the crack propagation action increased until it reached a level at which the crack continued to propagate without any additional stress (catastrophic failure), Figure (4) (Hamza et al, 2016).

This study suggests that, the laboratory technician could have the opportunity to design a connector area with sharp or narrow radius of curvature without affecting the strength of the restoration in the areas with enough occluso-gingival height, especially at the regions with limited spaces for increasing esthetic and function.

Conclusion

According to the results of the current

study, it had been concluded that the design of the connector showed a non-significant effect on the flexural strength of the (IPS e.max ZirCAD) FPD restoration.

Conflict of interest

We are the author's (Noor Adnan Abdul-Kareem, and Assist. Prof. Ihab Nafea Yassen) state that the manuscript for this paper is original, and it has not been published previously, and it is part of the MSc. dissertation and is not under consideration for publication elsewhere, and that the final version has been seen and approved by all authors.

References

AHMED, W. M., TROCZYNSKI, T., STOJKOVA, B. J., MCCULLAGH, A. P., WYATT, C. C. & CARVALHO, R. M. 2020. Dimensional Changes of Yttria-stabilized Zirconia under Different Preparation Designs and Sintering Protocols. Journal of Prosthodontics. https://doi.org /10.1111/jopr.13170

AKBARZADEH, A. 2019. Evaluation of the effect of connector size and design on flexural strength of monolithic zirconia fixed dental prosthesis. Tabriz University of Medical Sciences, School of dentistry. https://doi:10.34172/joddd.2020.039

ATTIA, A. & KERN, M. 2004. Influence of cyclic loading and luting agents on the fracture load of two all-ceramic crown systems. https://doi.org/10.1016/j.prosdent.2004.09.002

BAHAT, Z., MAHMOOD, D. & VON STEYERN, P. V. 2009. Fracture strength of three-unit fixed partial denture cores (Y-TZP) with different connector dimension and design. Swed Dent J, 33, 149-59.

BEUER, F., SCHWEIGER, J. & EDELHOFF, D. 2008. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. British dental journal, 204, 505. https://doi:10.1038/sj.bdj.2008.350

CLAUSEN, J.-O., ABOU TARA, M. & KERN, M. 2010. Dynamic fatigue and fracture resistance of non-retentive all-ceramic full-coverage molar restorations. Influence of ceramic material and preparation design. dental materials, 26. htt ps://doi.org/10.1016/j.dental.2010.01.011

FISCHER, H., WEBER, M. & MARX, R. 2003. Lifetime prediction of all-ceramic bridges by computational methods. Journal of dental research, 82, 238-242. https://d oi .org/10.1177/154405910308200317

HAMZA, T. A., ATTIA, M. A., EL-HOSSARY, M. M. K., MOSLEH, I. E., SHOKRY, T. E. & WEE, A. G. 2016. Flexural strength of small connector designs of zirconia-based partial fixed dental prostheses. https://doi.org/10.1016/j.prosdent.2015.06.022

HEINTZE, S., MONREAL, D., REIN-HARDT, M., ESER, A., PESCHKE, A., REINSHAGEN, J. & ROUSSON, V. 2018. Fatigue resistance of all-ceramic fixed partial dentures Fatigue tests and finite element analysis. https://doi.org/10.1016/j.d ental.2017.12.005

IVOCLARVIVADENT 2019. Product Information IPS E-Max System. Ivoclar Vivadent–worldwide. https://www.ivoclarvivadent.com/en/media-releases-products/

KANG, S.-H., CHANG, J. & SON, H.-H. 2013. Flexural strength and microstructure of two lithium disilicate glass ceramics for CAD/CAM restoration in the dental clinic. Restorative dentistry & endodontics, 38, 134-140. https://doi: 10.5395/rde.2013.38.3.134

KERMANSHAH, H., BITARAF, T. & GERAMY, A. 2012. Finite element analysis of IPS

Empress II ceramic bridge reinforced by zirconia bar. Journal of dentistry (Tehran, Iran), 9,196.

KOPELIOVICH, D. 2012. Flexural strength tests of ceramic. Substances and Technol ogies. https://www.substech.com/dokuwiki/doku.php?id=flexural_strength_tests_of_ceramics

KYPRAIOU, V., PELEKANOS, S. & ELIADES, G. 2012. Identification of monoclinic phase in CAD/CAM zirconia FPD frameworks. Eur J Esthet Dent, 7, 418-429.

LAKSHMI, R., ABRAHAM, A., SEKAR, V. & HARIHARAN, A. 2015. Influence of connector dimensions on the stress distribution of monolithic zirconia and lithium-di-silicate inlay retained fixed dental prostheses–A 3D finite element analysis. Tanta Dental Journal, 12, 56-64. https://doi. org/10.1016/j.tdj.2015.01.001

MALKONDU, Ö., TINASTEPE, N., AKAN, E. & KAZAZOĞLU, E. 2016. An overview of monolithic zirconia in dentistry. Biotechnology & biotechnological equipment, 30, 644-652. https://doi.org/10.1080/13102818.2016.1177470

MIURA, S., KASAHARA, S., YAMAUCHI, S. & EGUSA, H. 2017. Three-dimensional finite element analysis of zirconia all-ceramic cantilevered fixed partial dentures with different framework designs. European journal of oral sciences, 125,208-214. https://doi.org/10.1111/eos.123 42

MURASE, T., NOMOTO, S., SATO, T., SHINYA, A., KOSHIHARA, T. & YASUDA, H. 2014. Effect of connector design on fracture resistance in all-ceramic fixed partial dentures for mandibular incisor region. The Bulletin of Tokyo Dental College, 55, 149-155. https://doi.org/10.220 9 /tdcpublication.55.149

NASSEF, T. M., KHALIL, M. F. & KADER, S. H. A. Computer assisted to determine the influence of connector design and stress distribution in Incoris TZI (Zirconia) fixed partial denture. 2nd Middle East Conference on Biomedical Engineering, 2014. IEEE, 63-66. https://doi:10.1109/MECBME.2014.6783207

OGINO, Y., NOMOTO, S. & SATO, T. 2016. Effect of Connector Design on Fracture Resistance in Zirconia-based Fixed Partial Dentures for Upper Anterior Region. The Bulletin of Tokyo Dental College, 57, 65-74. https://doi.org/10.2209/tdcpublication.2015-0034

OH, W. S., GÖTZEN, N. & ANUSAVICE, K. J. 2002. Influence of connector design on fracture probability of ceramic fixed-partial dentures. Journal of dental research, 81, 623-627. https://doi.org/10.1177/1544059102081 00909

PLENGSOMBUT, K., BREWER, J. D., MONACO JR, E. A. & DAVIS, E. L. 2009. Effect of two connector designs on the fracture resistance of all-ceramic core materials for fixed dental prostheses. The Journal of prosthetic dentistry, 101, 166-173. https://doi.org/10.1016/S0022-3913(09)60022-6

REZAEI SM, HEIDARIFAR H, AREZODAR FF, AZARY A, MOKHTARYK HOEE S. 2011. Influence of Connector Width on the Stress Distribution of Posterior Bridges under Loading. J Dent (Tehran). Spring; 8(2):67-74.

RISMANCHIAN, M., SHAFIEI, S., NOURBAKHSHIAN, F. & DAVOUDI, A. 2014. Flexural strengths of implant-supported zirconia based bridges in posterior regions. The journal of advanced prosthodontics, 6, 346-350. https:/doi:10.4047/ja p.2014.6.5.346

SARANBABU, K. A., PERISETTY, D. K., THOTA, G., RASOOL, M., NIHARIKA, M. & SWAPNA, S. 2019. Influence of radius of curvature at gingival embrasure in connector area on stress distribution of three-unit posterior full-contour monolithic zirconia Fixed Partial Denture on various amounts of load application: A finite element study. Journal of International Society of Preventive & Community Dentistry, 9, 338. https://doi: 10.4103/jispcd.JISPC D2019

SCHERRER, S. S., LOHBAUER, U., DELLA BONA, A., VICHI, A., THOLEY, M. J., KELLY, J. R., VAN NOORT, R. & CESAR, P. F. 2017. ADM guidance—ceramics: guidance to the use of fractography in failure analysis of brittle materials. Dental Materials, 33, 599-620. https://doi.org/10.1016/j.dental.2017.03.004

SULAIMAN, T. A. 2020. Materials in digital dentistry—A review. Journal of Esthetic and Restorative Dentistry, 32, 171-181. https://doi.org/10.1111/jerd.12566

YAU, H., YANG, T. & LIN, Y. 2016. Comparison of 3-D Printing and 5-axis Milling for the Production of Dental e-models from Intra-oral Scanning. Computer-Aided Design and Applications, 13, 32-38. https://doi.org/10.1080/16864360.2015.1059186

ZARONE, F., FERRARI, M., MANGANO, F. G., LEONE, R. & SORRENTINO, R. 2016. "Digitally oriented materials": focus on lithium disilicate ceramics. International journal of dentistry, 2016. https://doi.org/10. 1155/2016/9840594

ZHANG, Y. & LAWN, B. 2018. Novel zirconia materials in dentistry. Journal of dental research, 97, 140-147. https://doi.org/10.1177/0022034517737483