Sapporo Medical Journal
Volume 57, Issue 03, March, 2023

FRACTURE RESISTANCE OF VENEERED PEEK CROWNS COMPARED TO VENEERED ZIRCONIA CROWNS UNDER THERMAL AND MECHANICAL CYCLIC LOADING (AN IN VITRO STUDY)

Ahmed hameed[1*], El Zahraa El-Dawakhly[2],Gihan El Naggar[2]

[1]Department of Fixed Prosthodontics, Faculty of Dentistry, Zagazig University.
[2]Department of fixed Prosthodontics, Faculty of dentistry, Cairo University.

.

Abstract— **Aim of the study:** The purpose of the present study was to assess fracture resistance of milled PEEK crowns veneered with composite compared to zirconia crowns veneered with porcelain under thermal and mechanical cyclic load. **Methodology:** A total of 20 veneered milled BioHPP and 20 veneered zirconia crowns were created and cemented on identical epoxy dies of prepared premolar. TCML was performed to simulate a one year period of oral service with 1200 thermal cycles (5°C/55°C) 2 min each cycle, 150000 mastication cycles at 49 N. After that the crowns were loaded to evaluate the fracture resistance. **Results:** Regarding to the fracture resistance test it was found that milled PEEK crowns showed the highest value (950.57 ± 123.26 N.) followed by veneered zirconia crowns (835.71 ± 245.14 N.). Statistical analysis showed non-significant difference between fracture resistance mean values (N) of the tested group. **Conclusions:**. Fracture resistance of veneered PEEK crowns was comparable to that of zirconia veneered crowns.

Keywords: Fracture**;** PEEK**;** zirconia

INTRODUCTION

Ceramo-Metalic restorations have been used in fixed prosthodontics for a long time and are still continuing successfully. However, with the increase in aesthetic expectations, these restorations fall short of meeting aesthetic needs of patients. In order to meet these aesthetic expectations, all-ceramic restorations became more common day by day. The aesthetic properties together with excellent biocompatibility and structural durability make the preference of all-ceramic restorations not only for the dentists but also for the patients.

Partially stabilized zirconia has been widely used as a substructure due to its excellent mechanical properties such as flexural strength and fracture resistance, which is considerably higher than those of other dental ceramics **Daou EE. (2014)** . Popularity of zirconia core-veneered all-ceramic restorations have been received, as it combines the esthetics of veneering glass ceramic and the strength of zirconia cores. The use of layering techniques allows dental ceramist to construct a highly aesthetic restoration with an individual character **Aboushelib MN. et al (2005)** .

Polyetheretherketon PEEK is a high-performance synthetic polymer that has been used for more than 30 years in human medicine as an implant material (finger prostheses, intervertebral discs and hip joint prostheses). Its benefits lie in the highly biocompatible material characteristic and its notable mechanical properties. Kurtz SM and Devine JN. (2007). PEEK has recently been introduced in dentistry, it has been used for the fabrication of implant fixtures, abutments, fixed and removable dental prosthesis frameworks, and for implant supported frameworks Stawarczyk et al (2015).

A modified PEEK material containing 20% ceramic fillers (BioHPP; Bredent GmbH) can be used for the fabrication of prostheses frameworks either by pressing or CAD-CAM milling procedures. Since it is not an aesthetic material, it cannot be used as a monolithic restoration, making an additional veneering process indispensable **Sproesser O. et al (2014)**.

The ability of veneered PEEK restorations to substitute veneered zirconia restorations in terms of fracture resistance is not yet fully investigated.

AIM OF THE STUDY

The purpose of the present study was to assess fracture resistance of milled PEEK crowns veneered with composite compared to zirconia crowns veneered with ceramic under thermal and mechanical cyclic loading.

NULL HYPOTHESES

The null hypotheses was that there will be no difference between veneered milled PEEK crowns in comparison to veneered zirconia crowns in terms of fracture resistance after thermal and mechanical cyclic loading

MATERIALS AND METHODS

Four specially designed Teflon molds were milled into the dimensions accommodating the chewing simulator four compartments. The 1st premolar of a maxillary typodont model (Frasaco UK 119, A-3 T; Franz Sachs & Co., Tettnang, Germany) was used in the present study. In order to simulate periodontal ligament resilience, the root of the tooth was dipped into dipping wax (GEO-Dip Renfert, Germany) then removed. This resulted in a wax layer on the root of the abutment tooth.

Epoxy resin (KEMAPOXY CAST CMB, Egypt) was mixed and poured into the Teflon mold. The tooth was mounted with its coated root vertically in the Teflon mold. After the epoxy resin had been set, a rubber index was taken using condensation silicon impression material (optosil, comfort kulzer, Germany)for the mounted tooth on the mold to ensure repositioning of the tooth at the same position after wax removal. The mold was heated in 65 C° water bath, the tooth was separated from the mold and an artificial socket was created within the epoxy resin.

The artificial socket was filled with polyether material (Impregum soft 3M ESPE, USA) and the tooth was mounted in its original place in the mold guided by the previously made rubber index. Two rubber indices were taken for the mold and the tooth, one of them was cut vertically and the other was cut horizontally to allow standardization of porcelain veneering of zirconia crowns. Also a transparent silicon index was taken using transparent additional silicon material (Visio.sil.ILTBredent, Germany) to allow standardization of composite veneering of PEEK crowns

The axial tooth preparation was done using a milling surveyor (BF2, bredent, Germany) and tapered with round end stone with a 2mm diameter tip (ValuDiamond V-856L/018SC). A circular deep chamfer finish line of a width 1.0 mm was made with 12 degrees total convergence. Occlusal reduction, functional cusp bevel and secondary plane were done manually with the help of the rubber indices and periodontal prob.

The tooth was removed from the mold, and the duplicating impression material (REPLISIL 22 N dent-e-con, Germany) was used to duplicate the prepared tooth into epoxy resin dies.

A total of forty dies were fabricated and divided into two groups according to the crown material into: Group I: milled PEEK veneered with composite (n= 20) and Group II (control group): zirconia veneered with ceramic (n= 20)

Optical impression was taken using extra oral scanner (DOF "Degree of freedom", South Korea) for each die of the milled PEEK group. Margin was detected, the cement space was adjusted to be 30 µm and the virtual coping was designed to be 0.6 mm. The STL files were forwarded to the CAM software where copings were nested within PEEK disc (bre.CAM Bio HPP Bredent, Germany) at the milling machine (CORiTEC, 350i loader pro, imes-icore, GmbH, Germany).
Afterward BioHPP copings were sandblasted with aluminum oxide (110 µ) then the Peek primer (visio.linkBredent, Germany) was applied on the BioHPP coping and cured using light curing unit (breLux power unit 2, bredent, Germany) for 90 seconds. Using 1:1 ratio the first dual curing opaqure (combo.lign, Bredent, Germany) was mixed and thinly applied to the coping as a wash opaquer then was polymerized for 180 seconds. Similarly, the second A2 opaquer (crea.lignOpaker 2, bredent, Germany) was applied and cured for 360 seconds

Using the transparent silicon index a thin layer of veneering composite E2 enamel (crea.lign, bredent, Germany) was painted inside the index then tack curing for 4 seconds. After that the index was filled with veneering composite A2 dentine and placed over the coping then was cured for 360 sec. Finally composite polishing kit (Visio.lign polishing kit, bredent, Germany) was used to polish the composite veneering

In order to fabricate zirconia crowns optical impression was taken in the same manner as previously mentioned, the construction STL files were forwarded to the milling machine, where copings were nested within partially sintered Y-TZP disc (Nacera Pearl 1 DOCERAM Medical Ceramics, Germany). After that sintering was done at sintering furnace (TS-2/M/ZIRKON-120 Furnace). The zirconia copings were veneered using feldspathic veneering porcelain (VM9 Vita Zahnfabrik, Germany). The veneeringprocess was carried out with help of vertically and horizontally cut rubber indices. Finally polishing was done followed by glazing cycle.

The epoxy models were sandblasted with aluminum oxide (50 µm) then a thin coat of universal adhesive(Scotchbond™ 3M ESPE, USA) was applied and cured. The fitting surface of BioHPP crowns were blasted with aluminum oxide (110 µm) followed by application of thin coat of PEEK primer (visio.link) and curing for 90 second. While the fitting surface of zirconia crowns were blasted with aluminum oxide (50 µm) after that a thin coat of 10-MDP zirconia primer (Z prime plus Bisco, USA) was applied and gently air blasted for 3-5 seconds then left for 5 min. before cementation.
A thin layer of cement (RelyX™ Ultimate 3M ESPE, USA) was applied over the bonding surfaces of the crowns. The crowns were seated slowly with gentle finger pressure on their corresponding dies. The crowns were placed for 3 minutes under a constant static load (3 Kg) using universal testing machine (Instron, USA).

Thermo-mechanical aging test was conducted using chewing simulator integrated with thermo-cycler (ROBOTA, Egypt). The four Teflon molds were embedded in the lower sample holder. A weight of 5 Kg, which is comparable to 49 N of chewing force exerted. The test was repeated 150.000 times. Accompanying all specimens were subjected during testing to simultaneous thermo-cycling between 5°C and 55°C for 1200 cycle with a dwell time of 60 seconds each with an intermediate pause of 10 seconds.

All samples were individually mounted on a universal testing machine with a load cell of 5 KN. The compressive force was applied occlusally until fracture. The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve recorded using computer software. The load required to fracture was recorded in newton.

Data represented as frequency (n), percentage (%), mean, standard deviation (SD), minimum, and maximum when appropriate. Fracture resistance data checked for normality using Shapiro Wilk test and showed normal distribution; so one-way ANOVA was used to compare between tested groups. Statistical Analysis was performed using IBM SPSS (version 26, Armonk, USA).

RESULTS

Results of the fracture resistance test:

When comparing fracture resistance mean value (N) for the different tested groups, it was found that CAD PEEK crowns showed the highest value (950.57 ± 123.26 N.), while veneered zirconia crowns scored (835.71 ± 245.14 N.)as presented in Table (1) and Figure (1).

Statistical analysis showed non-significant difference between the fracture resistance mean values (N) of the tested groups at ($p = 0.309 > 0.05$).

Table (1): Results of the fracture resistance mean value, standered deviation and confidance interval of the different tested groups.

Variable		Mean	SD	95% CI		ANOVA
				Low	High	p-value
Experimental group	CAD PEEK	950.57	123.26	896.55	1004.6	0.309 NS
	Veneered Zirconia	835.71	245.14	728.27	943.15	

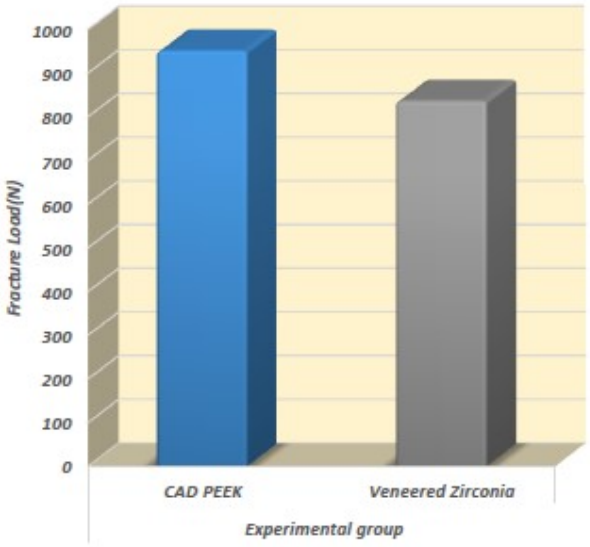

Figure (1): Column chart showing the results of the fracture resistance (N) of tested crowns with different materials type

Results of the core fracture of the different tested groups:

When comparing core fracture of different tested groups it was found that CAD PEEK scored (3 core fracture out of 20), also veneered zirconia scored (3 core fracture out of 20)

Statistical analysis showed non-significant difference between the different tested group at ($p = 0.189 > 0.05$) as presented in Table (2) and Figure (2).

Table: (2) Results of the core fracture of the different tested groups

Count Row %	Core fracture	Intact core	Total	p-value
CAD PEEK	3	17	20	0.189 NS
	15%	85%		
Veneered Zirconia	3	17	20	
	15%	85%		

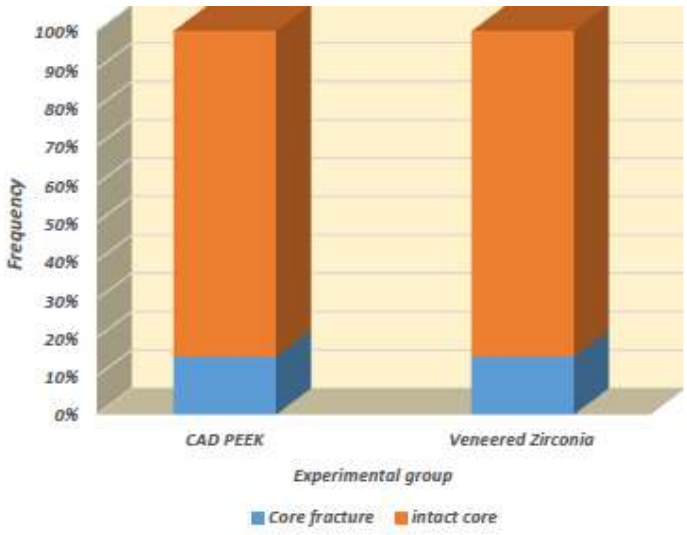

Figure (2): Stacked column chart showing results of the core fracture of the different tested groups.

DISCUSSION

In fixed prosthodontic treatment, the quest for an ideal restorative material that can mimic different shades of the human dentition and simultaneously be able to cumulatively withstand the masticatory loads without fatigue has been a utopia for prosthodontics. The increased need for more natural mimicking and strong restorations paved the way for the introduction of zirconia restorative material. Zirconia to a great extent, brought a renaissance to dentistry with the monolithic and layered variations. It has excellent mechanical properties which make it one of the most popular ceramic used in dentistry.

Despite the fact that veneered or layered zirconia restorations present a higher risk of chipping compared to monolithic restorations, some clinical situations necessitate its use such as cases of abutment teeth with metallic post and core, metal implant abutment and deep discoloration of the natural abutment teeth **Spazzin et al (2020)** . It's not yet known whether the BioHPP veneered restorations could be used as an alternative to zirconia veneered restoration in this regard. In addition the fracture resistance of BioHPP veneered restorations is not yet fully investigated.

That's why this study was carried out to assess the fracture resistance of veneered milled BioHPP crowns and comparing it to veneered zirconia crowns under thermal and mechanical cyclic loading.

veneered zirconia crowns was selected in the present study as its one of the most commonly used treatment modalities especially in clinical situation that require fine esthetic enhancement which could be attained by using layering technique of ceramic veneer.

In the present study BioHPP was also chosen because it is a restorative material suitable for veneered restorations, with mechanical properties comparable to zirconia **Ruchika S. Iyer et al (2020)**
The present study was conducted on upper premolar tooth as it is present in esthetic area and subjected to average biting force between molar and anterior teeth. The range of forces in maximum biting is 222-445 N in the premolar area **Phillips et al (1996).**

In the current study the Teflon mold was filled with epoxy resin to form the artificial alveolus as the modulus of elasticity of epoxy resin approximates that of human bone **W.Att et al (2006).**
The fracture analysis using immobile abutment die produced a much higher failure load than found when testing with mobile one. So in the present study periodontal ligament resilience was simulated according to **Beuer et al (2008)** by placing a polyether layer around the abutment roots simulating a periodontal resilience of 50–120 μm.

Two rubber condensation silicon indices had been taken for the mold and tooth, one of them was cut vertically and the other horizontally to allow thickness standardization of the porcelain veneered the zirconia crowns. Also a transparent silicon index was taken to allow thickness standardization of composite veneered the BioHPP crowns.

All ceramic preparation was carried out according to **Riedel et al (2019)** a deep chamfer finish line of a width 1.0 mm with 2mm occlusal reduction. In order to standardized the preparation the axial tooth preparation was done using tapered with round end stone mounted on milling surveyor since it could maintain the cutting axis exactly at the angle selected by controlling the taper precisely. Diameter of the tapered stone was checked by a digital caliper (2mm) to control the finish line thickness during reduction.

In the present study the axial preparation was made with 12 degrees total convergence angle because a convergence angle of five degrees is associated with the lowest fracture strength, and a 15 º or 20º convergence angle need greater tooth reduction **Doyle MG. et al (1990)**. also a 12 degree convergence was the most commonly used as reported by **Attia A. et al (2010)** and **Pilathadka S. et al (2007)**

The supporting die material has been reported to affect the fracture resistance of all-ceramic restorations **Yucel MT. et al (2012)**. In the present study the epoxy dies were used rather than natural teeth because it's difficult to standardize the dimensions of natural teeth even when abutment preparation is nominally identical. Epoxy dies were also selected because the modulus of elasticity of epoxy resin material is (4.7-4.9 GPa) which is close to that of dentine (8.7 to 11.2GPa) compared to other materials used for dies, e.g. aluminium (69 GPa) or resin (2-3 GPa) **Nordahl N. et al (2015)**. Also as reported by **Oilo et al (2013)** epoxy resin during occlusal load had the same elastic response and behave in a similar manner as dentin.

In the present study, all zirconia copings and CAD PEEK copings were designed and milled with the same CAD-CAM system to ensure standardization of all crowns

Hand layering technique was chosen in the current study because it is the most commonly used technique in dental laboratories and allow better individual characterization especially in difficult esthetic cases.

The crowns were cemented using adhesive dual cure resin cement in the present study as it provides better bond strength as reported by **Stamatacos and Simon (2013)** . It also offers effective control over the working time together with adequate degree of conversion, even in light absence under opaque restorations.

During the cementing procedures, a three kilograms load was applied using universal testing machine with rubber sheet placed between the crown and the metallic rod of the machine to minimize the cement film thickness as much as possible without jeopardizing the sample by applying an excessively large load and it allowed obtaining an even cement layer thickness for all crowns,. After removal of the excess cement, samples were light cured as was recommended by the manufacturer to ensure optimal polymerization.

Many studies performed thermo-mechanical loading as a hypothetical representation of the oral condition **Sterzenbach et al (2012)**. The aim of laboratory simulation is to predict the clinical performance of a material and the potential impact of each simulated variable on the results **Rosentritt M. et al (2006)**.

In the present study in order to simulate oral cavity conditions the thermo cycling process was done. The chemical effect of the water in weakening ceramic material has already been established by **Borges et al (2009)** and **Rekow D. and Thompson VP. (2007)**. the temperature range (5-55°C) was used in the present study as indicated by ISO standards to provide appropriate thermo cycling temperature extremes. The intermittent tension and compression that occur at the crack tip as a consequence of thermo cycling further increase the level of damage **Vult P. von Steyern et al (2006)**. According to **Rosentritt M. et al (2009)**, a load of 49 N. and a total of 750,000 mechanical cycles are necessary to simulate 5 clinical years. Based on this data, in the present study a load of 49 N. and a total of 150.000 cycles were performed to simulate 1 year of functional intra-oral services.

The present study was designed to be in vitro simulations because despite of the limitations of the in-vitro studies, they allow the evaluation of individual factors on the performance of the dental restorations under standardized conditions and it is also useful for time-lapsed testing of new materials in advance. **Hickel et al (2007)**.

Regarding the results of fracture resistance of the tested crowns the null hypotheses was accepted as there was no significant difference between fracture resistance mean values (N) of the tested groups. All tested crowns exceeded the fracture resistance required to withstand the normal masticatory forces in the premolar area which indicate that veneered CAD PEEK can serve well inside the oral cavity as well as veneered zirconia in term of fracture resistance

However these results are against the finding of **Nazari et al (2016),** who reported that the fracture load of veneered zirconia FDP. was significantly higher than PEEK FDP. This contradiction could be attributed to differences in the study design in term of restoration design, die material and aging process.

CONCLUSIONS & RECOMMENDATIONS

Within the limitations of this study, it was concluded that:

- Fracture resistance of veneered milled PEEK crowns was comparable to that of zirconia veneered crowns and exceeded the normal masticatory forces in the premolar area.
- Veneered BioHPP restorations can be used as an alternative of veneered zirconia restorations with regard to fracture resistance

Recommendation:

In cases of when there is a need to use an esthetic core veneered restorations, it is recommended to use milled BioHPP veneered with composite as an alternative to hand layered veneered zirconia restorations

REFERENCES

[1] **Aboushelib MN, de Jager N, Kleverlaan CJ, Feilzer AJ**.(2005) Microtensile bond strength of different components of core veneered all-ceramic restorations Dent Mater;21(10):984-91.

[2] **Anusavice KJ PR.** (1996.) Phillips' science of dental materials. 10th ed. Philadelphia: Saunders;

[3] **Att W, Kurun S, Gerds T, Strub JR**.(2006) Fracture resistance of single-tooth implant-supported all-ceramic restorations after exposure to the artificial mouth J Oral Rehabil;33(5):380-6.

[4] **Attia A**.(2010) Influence of surface treatment and cyclic loading on the durability of repaired all-ceramic crowns J Appl Oral Sci;18(2):194-200.

[5] **Beuer F, Steff B, Naumann M, Sorensen JA**.(2008) Load-bearing capacity of all-ceramic three-unit fixed partial dentures with different computer-aided design (CAD)/computer-aided manufacturing (CAM) fabricated framework materials Eur J Oral Sci;116(4):381-6.

[6] **Borges GA, Caldas D, Taskonak B, Yan J, Sobrinho LC, de Oliveira WJ**.(2009) Fracture loads of all-ceramic crowns under wet and dry fatigue conditions J Prosthodont;18(8):649-55.

[7] **Daou EE**.(2014) The zirconia ceramic: strengths and weaknesses Open Dent J;8:33-42.

[8] **Doyle MG, Goodacre CJ, Munoz CA, Andres CJ**.(1990) The effect of tooth preparation design on the breaking strength of Dicor crowns: 3 Int J Prosthodont;3(4):327-40.

[9] **Hickel R, Roulet JF, Bayne S, Heintze SD, Mjör IA, Peters M, Rousson V, Randall R, Schmalz G, Tyas M, Vanherle G**.(2007) Recommendations for conducting controlled clinical studies of dental restorative materials Clin Oral Investig;11(1):5-33.

[10] **International Organization for Standerdization**(ISO TR 11405)

[11] **Nazari V, Ghodsi S, Alikhasi M, Sahebi M, Shamshiri AR**.(2016) Fracture Strength of Three-Unit Implant Supported Fixed Partial Dentures with Excessive Crown Height Fabricated from Different Materials J Dent (Tehran);13(6):400-06.

[12] **Nordahl N, Vult von Steyern P, Larsson C**.(2015) Fracture strength of ceramic monolithic crown systems of different thickness J Oral Sci;57(3):255-61.

[13] **Øilo M, Kvam K, Tibballs JE, Gjerdet NR**.(2013) Clinically relevant fracture testing of all-ceramic crowns Dent Mater;29(8):815-23.

[14] **Pilathadka S, Vahalová D, Vosáhlo T**.(2007) The Zirconia: a new dental ceramic material. An overview Prague Med Rep;108(1):5-12.

[15] **Rekow D, Thompson VP**.(2007) Engineering long term clinical success of advanced ceramic prostheses J Mater Sci Mater Med;18(1):47-56.

[16] **Riedel C, Wendler M, Belli R, Petschelt A, Lohbauer U.**(2019) In vitro lifetime of zirconium dioxide-based crowns veneered using Rapid Layer Technology Eur J Oral Sci;127(2):179-86.

[17] **Rosentritt M, Behr M, Gebhard R, Handel G.**(2006) Influence of stress simulation parameters on the fracture strength of all-ceramic fixed-partial dentures Dent Mater;22(2):176-82.

[18] **Rosentritt M, Behr M, van der Zel JM, Feilzer AJ**.(2009) Approach for valuating the influence of laboratory simulation Dent Mater;25(3):348-52.

[19] **S Iyer R, S.R S, Hegde D, A Coutinho C, PriyaAJJoRiD**.(2020) BIOHPP: PROPERTIES AND APPLICATIONS IN PROSTHODONTICS A REVIEW 7:72-76.

[20] **Spazzin AO, Schestatsky R, Ness CRB, Alessandretti R, Pereira GKR**.(2020) Obtaining optimal esthetics with veneered zirconia and lithium disilicate frameworks on substrates of different colors J EsthetRestor Dent;32(6):540-44.

[21] **Sproesser O, Schmidlin PR, Uhrenbacher J, Roos M, Gernet W, Stawarczyk B**.(2014) Effect of sulfuric acid etching of polyetheretherketone on the shear bond strength to resin cements J Adhes Dent;16(5):465-72.

[22] **Stamatacos C, Simon JF**.(2013) Cementation of indirect restorations: an overview of resin cements CompendContinEduc Dent;34(1):42-4, 46.

[23] **Sterzenbach G, Rosentritt M, Frankenberger R, Paris S, Naumann M.**(2012) Loading standardization of postendodontic restorations in vitro: impact of restorative stage, static loading, and dynamic loading Oper Dent;37(1):71-9.

[24] **Vult von Steyern P, Ebbesson S, Holmgren J, Haag P, Nilner K**.(2006) Fracture strength of two oxide ceramic crown systems after cyclic pre-loading and thermocycling J Oral Rehabil;33(9):682-9.

[25] **Yucel MT, Yondem I, Aykent F, Eraslan O**.(2012) Influence of the supporting die structures on the fracture strength of all-ceramic materials Clin Oral Investig;16(4):1105-10.