COMPARISON OF LOAD BEARING CAPACITY OF POLY ETHER ETHER KETONE (PEEK) SINGLE CROWNS FABRICATED BY TWO DIFFERENT TECHNIQUES (AN IN-VITRO STUDY)

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Abstract

Aim: To test and compare the impact of two different fabrication methods on the load-bearing capacity of full anatomical peek crowns.

Methodology: Total of n=20 PEEK crowns were constructed by 2 different fabrication methods and divided in to 2 groups n=10 (PEEK CAD and PEEK Pressed). All crowns were constructed over a master die. For the PEEK CAD crowns, the master die scanned by 3shape E4 scanner TRIOS®3. And designing was done by Ceramill4E2 Exocad CAD/CAM Software and using 4 –axis milling machine. For the PEEK pressed crowns, Wax copings were milled using the same STL file with the same dimensions used for designing, and milling of the previously constructed CAD PEEK Crowns. Auto polymerized resin was used to produce 20 duplicate resin dies, the fitting surface of all crowns of both groups was sandblasted with 110-μm alumina particles. All crowns were cemented over their corresponding epoxy dies using the (hand-mixed) dual-cured, self-adhesive resin cement (RelyX™ U200) (3-kg seating force). Samples were subjected to mechanical aging (75,000 cycles, 50 N load) with simultaneous thermocycling (2500 cycles, 5-55°C, 25 s dwell time). All samples were individually mounted on a computer-controlled (universal testing machine) (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 N till failure were recorded. The load required to fracture was recorded in Newton and failure modes were observed and recorded using Scanning Electron Microscope

Results: It was found that CAD\CAM PEEK group recorded statistically non-significant higher mean value with M=2213.3 (SD=275.88) than PRESS group with M=2108.5 (SD=235.89). In CAD group the failure mode patterns were predominantly repairable (80%) with minor record for catastrophic one (20%). While in Press group all samples showed repairable failure mode pattern (100%) with no record for catastrophic one (0%). The difference in the failure modes recorded for both groups was statistically significant as revealed by chi square test (p=<0.0001<0.05).

Conclusion: In this study. CAD/CAM fabricated monolithic single crown presented a higher mean fracture load than those pressed from pellet PEEK/C material but with no statistically significant difference.

Keywords: PEEK, CAD-CAM, Press, fracture resistance, thermomechanical.

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Introduction

The main purpose of fixed prosthetic medical specialty is to use artificial materials to rehabilitate deficiencies within the teeth and oral tissues. Despite significant research efforts, it is still impossible to declare that a superior material exists that can satisfy all of the expectations of physicians.

As a result, research is still being done to determine the best material to use and how to get it. Because of their better mechanical qualities, appealing aesthetics, outstanding patient compliance, colour stability, high abrasion resistance, and low thermal conductivity, all-ceramic restorations are now viewed as a viable alternative to metal-ceramic restorations. [1].

These materials, such as lithium disilicate and yttria-stabilized zirconia, have been developed together with new processing processes to permit their application in the prosthetics area; nonetheless, their brittleness and the sufficiency of their accuracy have been questioned. To overcome the latter problem, a new generation of composites in the field of prosthetic dentistry has been introduced as a promising alternative to all-ceramic materials, known as PAEK (polyaryletherketone),PEEK(polyetheretherketone),PEKK(polyetherketoneketone) materials [2][3]

They serve as substitutes for metal and ceramic-based restorations and are examples of high-performance polymers used in dental restorative materials. They have recently been explored as a restorative material for fixed appliances, either solid or bi-layered structures with composite resin veneers [4][5]

With a glass transition temperature of roughly 143oC, PEEK is extremely resistant to thermal deterioration in addition to having great biocompatibility. It has a melting temperature of approximately 334oC and a modulus of elasticity of 3–4 GPA, which describes the resistance of the material against flexible deformation that is similar to human bone.[6]

In the dental field, despite the lack of long-term clinical studies, PEEK has been used in implantology as implant bodies, implant abutments and interim restorations, and implant-supported hybrid prosthesis [7]

PEEK has a 140–170 MPA bearing capacity, making restorations less prone to bulk fractures. According to studies, PEEK can be used to create crowns in reconstructive dentistry because of its comparable tensile strength (80

MPA) to dentin (104 MPA) and enamel (47.5 MPA) [8].

For the purpose of creating fixed and removable prostheses, highly efficient thermoplastic polymers based on PEEK have been brought to the market. They can be delivered as ingots for hot pressing, pellets for injection moulding, or blanks for CAD/CAM milling.[9]

There is limited information about the influence of fabrication technique on the loading bearing capacity of monolithic PEEK restorations. So, the aim of this study is to test and compare the effect of two different fabrication methods on the load-bearing capacity of full anatomical peek's crowns

Materials and Methods

1.1Trial design: A comparative in vitro study.

2.1 Ethical considerations:

The ethics committee (EC), Faculty of Dentistry, Cairo University, accepted the invitro study protocol in terms of its scientific substance and compliance with the laws and regulations governing practice with human subjects. The approval number was 5-9-20

3.1 Sample size calculation:

A power analysis planned to apply a statistical test of the null hypothesis that no differences in resistance to fracture of PEEK crowns using various fabrication methods. An alpha level of (0.05) a beta of (0.2) i.e., power=80% and an effect size (d) of (1.43). The predicted sample size (n) was a total of (18) samples. Sample size calculation was performed using G*Power version 3.1.9.7.

4.1 Samples grouping

Typodont was restored by full anatomical PEEK crowns that were divided into two groups according to the method of fabrication used. PEEK crowns were numbered from 1-20. PEEK CAD crowns were numbered from 1-10 While PEEK Pressed crowns were numbered from 11-20, where each group has 10 crowns and both are constructed over the master die.

2.Preparation on a master die

To accept PEEK crowns, the typodont mandibular molar tooth was prepared. (4.5 mm in height, 1.0 mm in width) with chamfer finish line, and 10 degrees for the overall angle of convergence and a mean of 6 degrees convergence of the axial walls. Gross preparation was done by employing a single tapered stone. The stone's tapering edge's diameter 1 was TR 12 medium grit blue band. Finish line thickness was checked using a periodontal probe and degree of taper was checked after finishing of the preparation using AF 30 NOUVAG device.

1.2. Fabrication of Epoxy dies

A specially designed metal cylinder (ring) (30 mm long, 17mm inner diameter) was used as a tray to hold 20 silicon molds for the typodont master die to produce 20 epoxy replica dies. After fixation of the typodont master die in aplastic base at the end of the metal cylinder tray REPLISIL 22 N Duplicating silicone material was used to produce molds then Auto-polymerizing epoxy resin, was poured into the mold under vibration. following manufacturer's instructions. Figure [1]

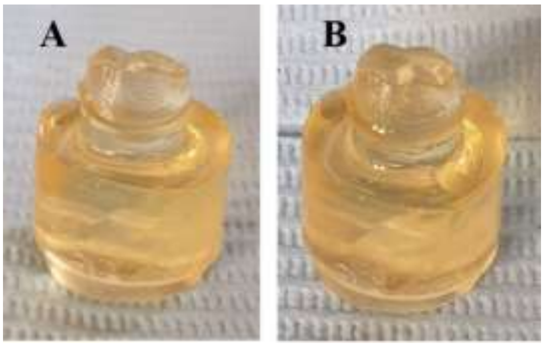


Figure [1] epoxy resin die

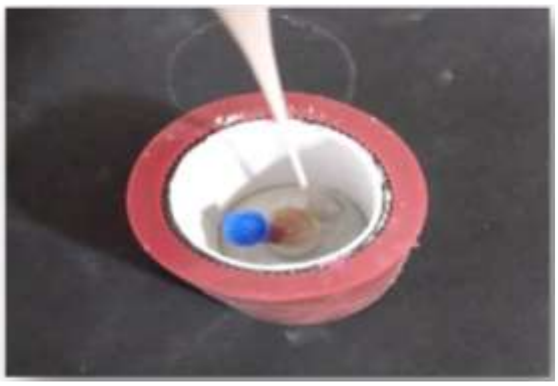
2.2. Fabrication of PEEK crowns Acquisition and Designing: An extra-oral optical scanner was used for scanning the die using las er technology. The typodont was placed in the multi-die holder to be scanned by 3shape E4 scanner TRIOS®3 (3Shape) A/S **and** designing was done by Ceramill4E2 Exocad CAD/CAM Software and a virtual image of the prepared tooth was obtained. To ensure standardization, the same design parameters were set for all fabricated crowns. All crowns were designed to have identical external contours.

3.2Construction of PEEK crowns using CAD/CAM Blanks (Comparator group): With a homogeneous wall thickness of 1.5 mm, the material thickness was standardised, 1mm above the finish line, a 50-mm virtual cement layer was placed. The gathered information was forwarded to a 4-axis milling machine (CORI TEC 350i PRO), where a milling blank (98.mm) was used to create PEEK CAD Crowns (n=10). Figure [2]

Figure [2] CAD/CAM crown

4.2. Construction of PEEK Crowns from pressing technique using Pellets (Intervention group)

Wax c rowns (n=10) were scanned, developed, and milled from the same STL file with the same dimensions as the CAD-CAM PEEK Crowns that were previously constructed. As directed by the manufacturer in a silicone mold, 4mm length and 4mm diameter sprues attached to wax copings and invested in a phosphate bonded investment (Brevest; Bredent). Figure [3]



PEEK pellets in an Ibex dental furnace (A 130) for wax removal, and then allowed to cool at a rate of 8°C/minute to 400°C. After the silicon mold had been filled with the PEEK pellets, the crowns were then pressed using a single disposable plunger for each muffle at 0.45 MPa pressure for PEEK pellets in a vacuum pressing

5.2. Verification

A steam cleaner was used to clean every cro wn. The crowns were then modified to fit the master die until the highest level of precision was attained. The margins are checked by using magnifying lens and any error in seating or any defects existed. They are rejected from the samples.

3. Cementation protocol

1.3. surface treatment of PEEK

Aluminum oxide particles measuring 110 µm were used to sandblast the inside surfaces of the crowns in both groups inside sandblaster 0.2MPa at a range of 10mm and for ten seconds, vertically to the surface. PEEK crown held in special wooden holder at a fixed distance from sandblasting nozzle, inside sandblaster. The crowns were then liberally air-sprayed. They were then cleaned for 2 minutes in an ultrasonic cleaner before being dried in accordance with the manufacturer's instructions.

2.3. Cementation procedure.

Using dual-cured self-adhesive resin, all crowns were glued to their appropriate dies following manufacturer's specifications. Over the mixing pad, the cement clicker was used to dispense equal amounts of the base and

Figure [3] investing wax coping of preesd peek crown

equipment (For 2 presses; Bredent). Upon casting, a PEEK pressed crown is produced following full solidification. After 10 minutes of steam cleaning with a 3M Sofflex disc, the cro wns were done.

catalyst pastes. 2 clicks were used for cementation of each crown. Mixing was done using a stainless-steel spatula for 20 seconds,

Figure [4] Cementation device holding specimen and applying vertical load

The cement was evenly distributed on the intaglio crown surface with a pen brush. Then, by using the most finger pressure, crowns were positioned over the corresponding dies. The crowns were held in place and subjected to a 3 kg constant static axial load using a specially made cementing tool. Figure [4]

3.3.Storage of samples

All samples were stored in distilled water storage in an incubator11 for **24 hours** at **37o c.**

4.3. Thermomechanical aging

The simulation of chewing was run 75,000 times with a capacity of **5kg (50N)** weight. Under regulated test conditions, a load was applied to the centre of the occlusal surface of every crown using the steel antagonist ball. This is remarkably comparable to Six months of in-person service. **(Rosentritt et al., 2015; Güngör et al., 2019).** This was done while simultaneously thermocycling in deionized water. Table [1]

Table (1). Chewing simulation test parameters

Vertical movement: **1mm**	Horizontal movement: **3mm**
Rising speed: **90mm/s**	Forward speed: **90mm/s**
Descending speed: **40mm/s**	Backward speed: **40mm/s**
Cycle frequency: **1.6Hz**	Weight per sample: **5kg**
Torque: **2.4N.m**	

4.Fracture Resistance measurement

Samples were secured to the lower fixed compartment of testing machine by tightening screws. Fracture test was done by compressive mode of load applied occlusally using a metallic rod with spherical tip (5.6mm diameter) attached to the upper movable compartment of testing machine traveling at crosshead speed of 1mm/min with tin foil sheet in-between to achieve homogenous stress distribution and minimization of the transmission of local force peaks. Figure [5]

The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve recorded using computer software (Bluehill Lite Software Instron® Instruments). After fracture resistance test, specimens in each test groups were viewed using a USB digital-microscope images were taken at maximum resolution (2272 · 1704 pixels) and connected with an IBM compatible personal computer using a fixed magnification of 25X**.** Then viewed under a scanning electron microscope.

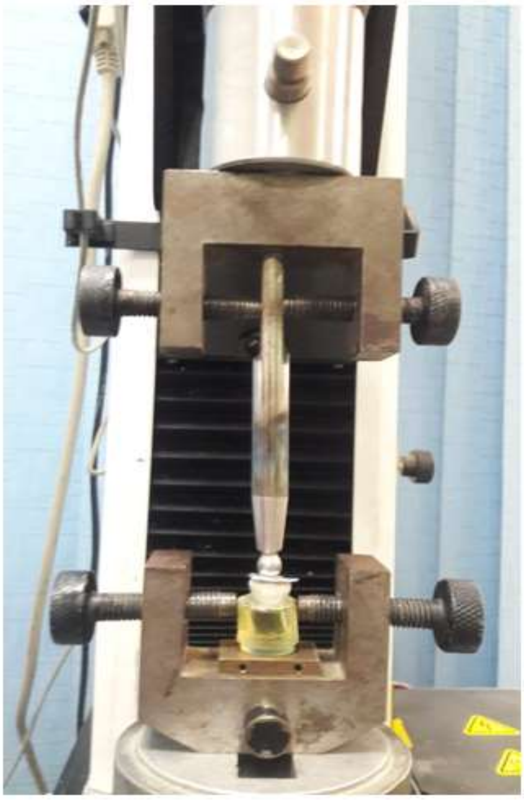


Figure [5] Universal Testing Machine (Instron™)

RESULTS

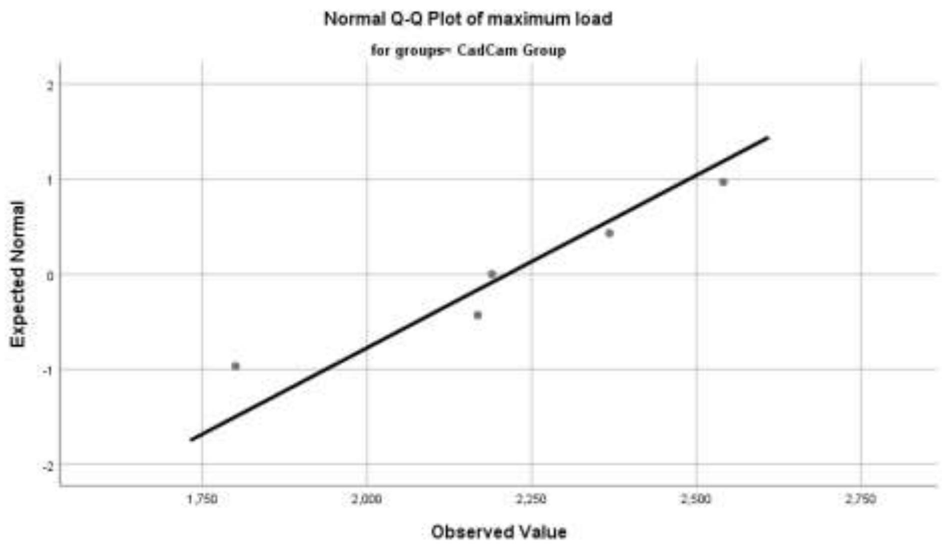
I-Statistical Analysis for Load Bearing Capacity.

1. Checking The Normality of the data

Using Kolmogorov-Smirnov test and Shapiro-wilk's test for checking the normality of the data followed by a visual inspection of the histograms indicated that the maximum load was normally distributed for both study groups (CAD\CAM and PRESS groups). Assuming that significance value ($p>0.05$) of these normality tests indicates normal distributed data. The Kolmogorov-Smirnov test revealed that the P-value was 0.2 in CAD group and 0.2 in PRESS group. Also the Shapiro-Wilk test revealed that the P-value was 0.81 CAD group and 0.82 in PRESS group. table [1]

Table (1): showed results of the normality tests for the study groups

Tests of Normality							
	study groups	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Maximum load	CAD\CAMgroup	0.23	5	0.2	.96	5	0.81
	Press group	0.19	5	0.2	.96	5	0.82



2. <u>Parametric Test (Independent t-test):</u>

The Cad Cam group was recorded to be associated with maximum load values with M=2213.3 (SD=275.88). By comparison, the maximum load values in PRESS group were recorded to be with M=2108.5 (SD=235.89). To test the hypothesis that Cad Cam and PRESS groups were associated with statistically significant difference of their means, an independent t-test was performed as seen in Table [2] and Figure [6]Additionally, the assumption of homogeneity of variance was tested via Levene's test, F=0.006 and significance value (0.94) indicating that equal variances are assumed in both study groups.

Independent t- test revealed that there is no statistical significant difference between CAD/CAMgroup and PRESS group with recorded P- value **=0.54 at df =8**.

Table (2): Illustrating the independent t-test results of the study groups

Group Statistics								
	Study groups	Levene's test		t-value	df	P-value (2-tailed)	95% confidence interval of the difference	
		F-value	Sig.				Upper	Lower
Maximum load	CAD\CAM group	0.006	0.94	0.65	8	0.54	-269.53	479.15
	PRESS group						-271.10	480.73

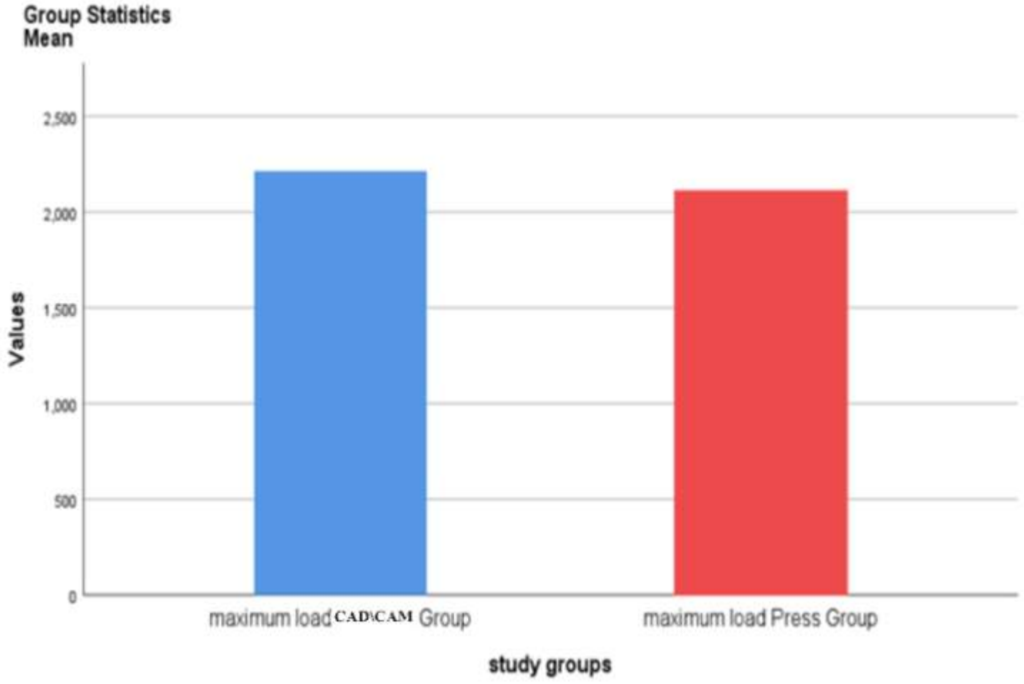


Figure (6): Bar chart representing the mean values of the maximum load in the study groups.

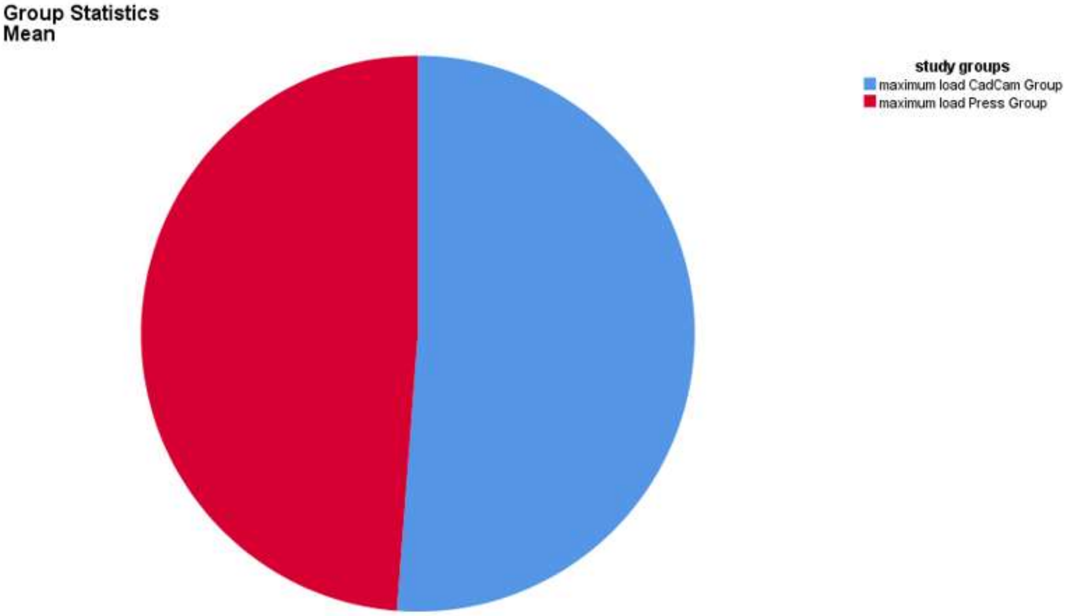


Figure (7): A pie chart representing mean values of the maximum load in the study groups

Failure mode observation

Failure modes were observed and recorded. Evaluations were based on two modes as listed in **table(3)** and graphically drawn in **figure (8)** .In CAD group the failure mode patterns were predominantly repairable (80%) with minor record for catastrophic one (20%). While in Press group all samples showed repairable failure mode pattern (100%) with no record for catastrophic one (0%). The difference in the failure modes recorded for both groups was statistically significant as revealed by chi square test (p=<0.0001<0.05).

Table (3): Frequent distribution of failure mode patterns in both groups

Variable		Failure mode patterns	
		Repairable (Restoration only)	Catastrophic (Restoration and die)
Processing technique	CAD	80%	20%
	Press	100%	0%
Chi square test		*P value*	<0.0001*

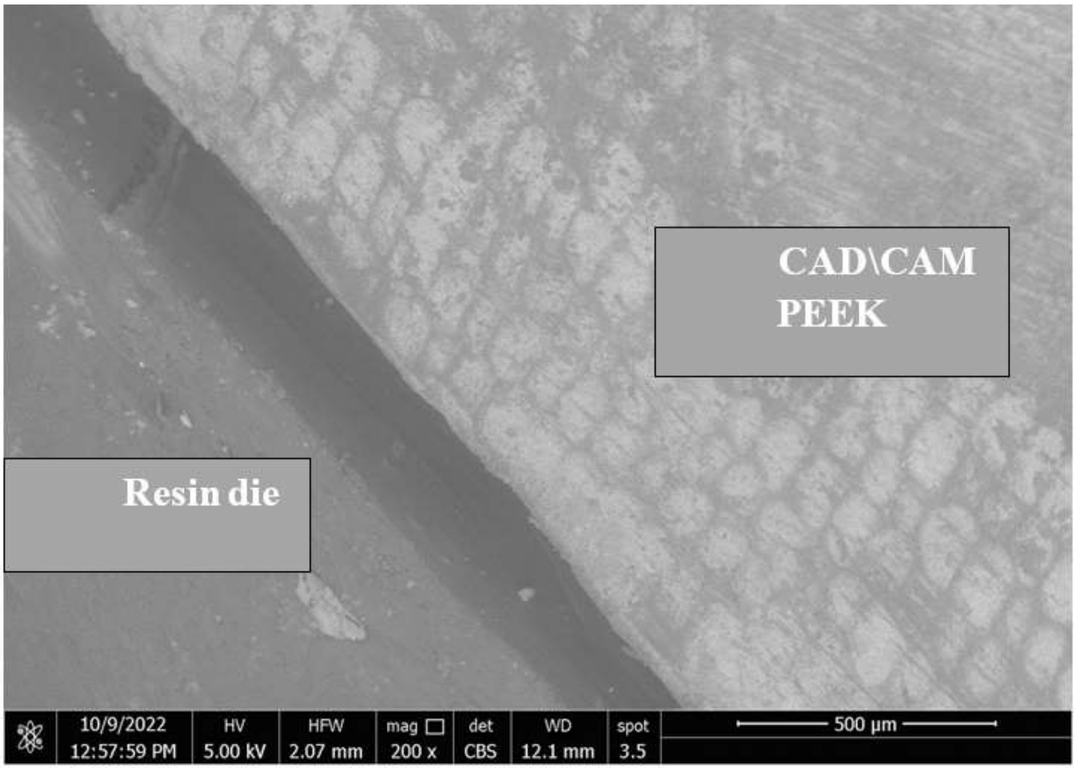


Figure (9): Scanning electron microscope image at magnification 200x showing a catastrophic failure showing the interface between peek crown and die in CAD CAM GP

Scanning electron microscope images

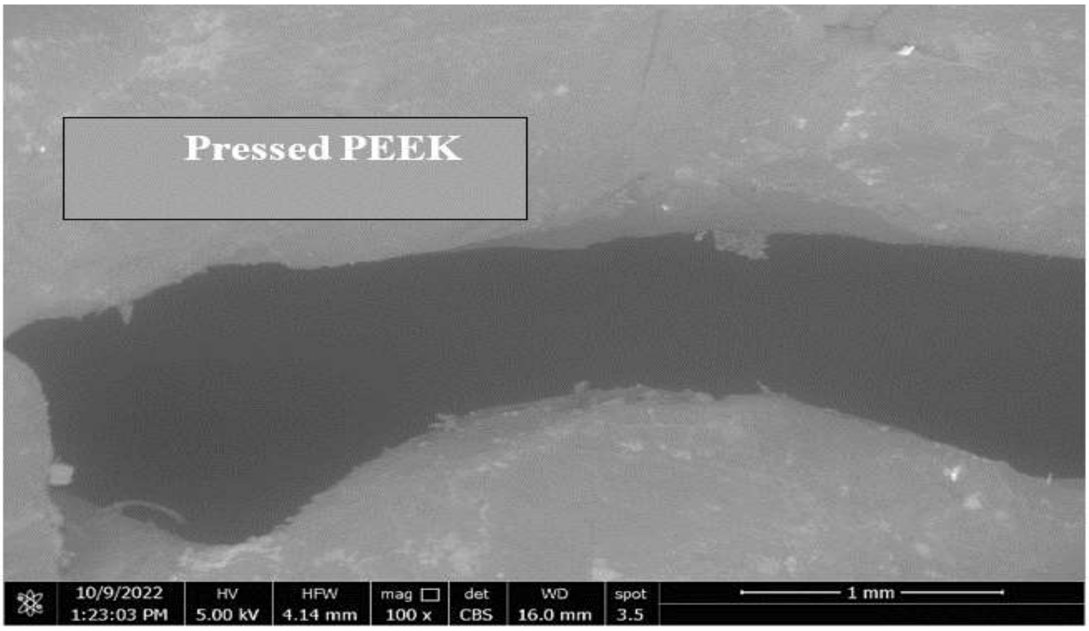


Figure (11): Scanning electron microscope image at magnification 200x representing a cohesive failure (repairable) in the peek crown pressed GP

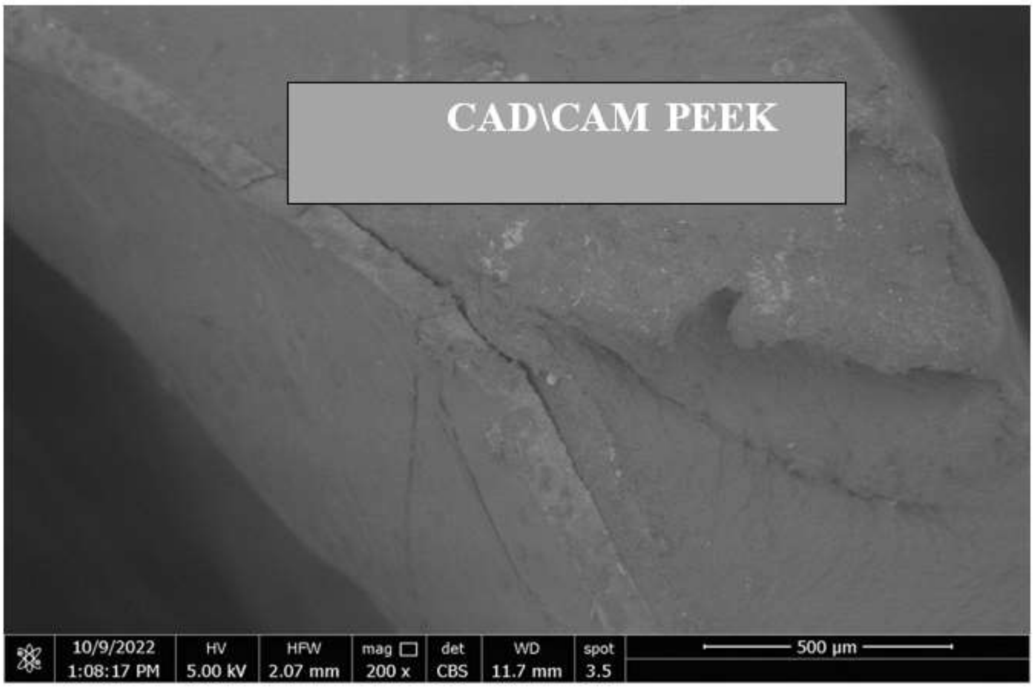


Figure (10): Scanning electron microscope image at magnification 200x representing a cohesive failure (repairable) in the peek crown CAD CAM GP

DISCUSSION

As a high-performance thermoplastic polymer, PEEK, a prominent member of the PAEK polymer (Polyaryletherketone) family, was introduced in the dental industry throughout the 1990s as the major replacement for the metallic components for implants, particularly in cases of orthopaedics and trauma. It demonstrated that it has great thermal and chemical stability, is simple to manufacture, is non-toxic, and is radiolucent naturally. [10]

PEEK can be modified to improve its mechanical properties by incorporating particular materials. For instance, adding carbon fibres can boost elastic modulus by up to 18 GPa, as can beta-tricalcium phosphate, hydroxyapatite, or titanium dioxide. This substance, which is castable under pressure and heat, as well as CAD-CAM knowledge and the wax waste management technique.[11][12]

The main distinguishing quality of PEEK is that it has a low elasticity modulus that is comparable to bone. It has been claimed that this material's low elasticity modulus could help mitigate stress-related issues. This evidence suggests that PEEK material might be an alternative. to ceramic crowns pertaining to dentistry.[13]PEEK is extremely stiff and has a flexural strength between 140 and 170 MPa. There are also fewer magnetic resonance imaging artifacts. The fact that PEEK does not wear down the adjacent natural teeth is another fantastic benefit. United States FDA Drug & Device Master Files attest to its biocompatibility and biostability.[14]

Presently, PEEK is employed in dentistry for a broad range of purposes, including implant-supported hybrid prostheses, detachable prostheses, fixed partial dentures, temporary implant abutments, and implant healing caps.[15]

PEEK is a dental material with excellent mechanical properties. In comparison to lithium disilicate crowns, it demonstrated a stronger fracture resistance and a much higher capacity to absorb occlusal loads without showing any signs of failure.

In the fatigue life test, solid PEEK crowns outperformed clinically successful lithium disilicate crowns in terms of survival rate and catastrophic failure mode in tests with substantially greater fatigue loads.[16]

Despite advancements in CAD/CAM technology, marginal fit, fracture resistance, and aesthetics remain the three key determinants of restorative success. Additionally, it is crucial to consider a restorative material's mechanical characteristics and load to fracture in order to choose one that will withstand chewing pressure and safeguard the tooth structure.[17]

A specialised vacuum-pressing apparatus can be used to press PEEK. PEEK is utilised for this purpose either in granular form or as industrially pre-pressed pellets. Both are the same in composition (80% PEEK with 20% nanoceramic filler) and method of fabrication but differ in the size of their particles, where pellet particles are slightly larger. The vacuum-pressing equipment is used to push the heated muffle (with the press plunger) during the pressing operation.[18]

The aim of the current study was to test and compare the impact of two different fabrication methods on the load-bearing capacity of full anatomic PEEK crowns manufactured using pressing techniques (intervention group) and CAD/CAM techniques (comparator group) .

For standardisation of all samples, a single typodont die was prepared to receive a single crown by the same operator. A silicone putty index was made for the typodont before preparation as well as split in the direction of the buccolingual to check the amount of reduction and degree of taper. These were checked after the preparation was finished by means of a parallel-meter device to guarantee a uniform preparation [19]

Duplicate epoxy resin dies were preferred to natural teeth for the purpose of standardization since natural teeth exhibit inherent variations in type, shape, size, microstructure, age, as well as storage conditions, which would inevitably affect the mechanical outcome.[20][21][22]

We created a CAD/milling of wax patterns for the pressed group from similar STL files used for designing milled PEEK crowns (huge casting single pack wax). Utilizing the identical CAD group milling parameters to maintain uniformity of cement gap and crown width As well, each wax pattern for each constrained crown was committed to investing and pressing.While finishing and polishing was done for both groups by one operator. [23]

Concerning surface treatment of both groups, sandblasting was done vertically to the crowns' internal surface to avoid uneven reduction of the surface; mainly the inner occlusal surface could suffer more reduction. For both groups, airborne particle abrasion using 110-m alumina particles at 0.2 MPa pressure was used. For the sake of standardisation PEEK crowns held in special wooden holder at a fixed distance 10mm from airblaser nozzle . It was also recommended by the manufacturers of both BioHPP™ PEEK This regimen was additionally proven, to achieve the best results for shear bond strength and surface roughness with a variety of materials.[24][25][26]

The chosen cement, which is an MMA monomer-containing adhesive system (RelyX™ U200 Clicker™), it is typically advised to strengthen the binding with PEEK material even after ageing, particularly after sandblasting.[26][27]Uhrenbacher et al., 2014; Stawarczyk et al., 2013). It is thought that these acidic monomers will copolymerize with the commercially available CAD/CAM resin **(Stawarczyk et al., 2012)**. Moreover, **Ates et al., (2018)** added that, under SEM, sandblasting produced larger irregularities than other surface treatments on a PEEK surface, without irregular undercuts, which are thought to be appropriate for adhesive resin flow. Using a pen brush, the cement was evenly applied to the surface of the intaglio crown.[28]

In this study, the loadbearing results demonstrated that all groups could withstand physiological occlusal forces with appropriate fracture strengths. (The maximum load values in the CAD/CAM group were recorded to be M = 2213.3 (SD = 275.88). By comparison, the maximum load values in the PRESS group were recorded at M = 2108.5 (SD = 235.89), and the P-value of 0.54 indicates that there is no statistically significant difference between the CAD/CAM group and the PRESS group.

The present study was coincident with the previous stud study. by **Stawarczyk et al. (2015)**,who investigated the loadbearing capacities and failure types for three units of PEEK FPDs fabricated using various techniques. CAD/CAM-milled PEEK (2354 N) had a higher mean fracture load than did those come from granular PEEK material (1738 N). So, the null hypothesis, assuming that no significant difference would be found in the load bearing capacity between CAD/CAM and PRESS PEEK crowns, is accepted.

Concerning failure modes for PEEK crowns, in the CAD group, the failure mode patterns were predominantly repairable (80%), with a minor record for catastrophic ones (20%). While in the Press group, all samples showed a repairable failure mode pattern (100%) with no record for a catastrophic one (0%), as found by **Shirasaki et al.2018**.[29]

CONCLUSIONS

Within the limitations of this study it could be concluded that :

1. CAD/CAM-fabricated monolithic single crowns exhibited a greater mean fracture load compared to those pressed from PEEK pellets.
2. The maximum load values of both the CAD/CAM-fabricated monolithic single crown and the pellet-pressed PEEK material are considered clinically acceptable.
3. A fixed dental prosthesis could use PEEK as a single posterior crown.

RECOMMENDATIONS

Regarding researchers

1.Further studies involving natural teeth as substrates and having more prolonged ageing regimens are recommended for comparison as well as for further assessment of the material. However, an adequate sample size should be considered to overcome the inherent variability involved with natural teeth.

2.More future studies regarding other properties of PEEK, e.g., hardness, color, etc., are expected for a better understanding of the material, especially in the long term. Also, to assure its suitability for clinical use.

Regarding clinicians

Upon the results of our study, it is better to use pressed-peek from pellets as it has a lower rate of catastrophic failure and, regarding its load-bearing capacity, there is no significant difference between the two different techniques of fabrication.

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References

[1] Attia, M. A., & Shokry, T. E. (2020). Effect of different fabrication techniques on the marginal precision of polyetheretherketone single-crown copings. Journal of Prosthetic Dentistry, 124(5), 565.e1-565.e7. https://doi.org/10.1016/j.prosdent.2020.04.003

[2] Alshalan,A.,Almutair,A.,Awad, D.,Alshmlani,M.,Abbas,S.Bin,& Asif, Z.(2019).International Journal of Dentistry and Oral Health Marginal and Internal Fit of CAD CAMSystem. 5(3), 39–47.

[3] Stawarczyk, B., Eichberger, M., Uhrenbacher, J., Wimmer, T., Edelhoff, D., & Schmidlin,P. R. (2015). Three unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dental Materials Journal, 34(1), 7–12. https://doi.org/10.4012/dmj.201 3-345

[4] Tannous, F., Steiner, M., Shahin, R., & Kern, M. (2012). Retentive forces and fatigueresistance of thermoplastic resin clasps. Dental Materials, 28(3), 273–278. https://doi.org/10.1016/j.dental.2011.10.016

[5] Rosentritt, M., Preis, V., Behr, M., Sereno, N., & Kolbeck, C. (2015). Shear bond strength between veneering composite and PEEK after different surface modifications. Clinical oral investigations, 19(3), 739–744. https://doi.org/10.1007/s00784-014-1294-2.

[6] Saja A. Muhsin., Paul V. Hatton., Anthony Johnson., Nuno Sereno., Duncan J. Wood.,(2019) Determination of Polyetheretherketone (PEEK) mechanical properties as a denture material Saudi Dental Journal (2019) 31, 382–391

[7] Mishra, S., & Chowdhary, R. (2019). PEEK materials as an alternative to titanium in dental implants: A systematic review. Clinical implant dentistry and related research, 21(1), 208-222.

[8] Georgiev, J., Vlahova, A., Kissov, H., Aleksandrov, S., & Kazakova, R. (2018). Possible Application of Biohpp in Prosthetic Dentistry: a Literature Review. Journal of IMAB – Annual Proceeding (Scientific Papers), 24(1),1896–1898. https://doi.org/10.5272/jimab.2018241.1896

[9] Najeeb, S., Zafar, M. S., Khurshid, Z., & Siddiqui, F. (2016). Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. Journal of Prosthodontic Research, 60(1), 12–19. https://doi.org/10.1016/j.jpor.2015.10.001

[10] El-Ashkar, A., Taymour, M., & El-Tannir, A. (2021). Evaluation of the marginal and internal gaps of partially crystallized versus fully crystallized zirconia-reinforced lithium silicate CADCAM crowns: An in vitro comparison of the silicone replica technique, direct view, and 3- dimensional superimposition analysis. Journal of Prosthetic Dentistry, 1–8. https://doi.org/10.1016/j.prosdent.2021.07.024

[11] Najeeb, S., Zafar, M. S., Khurshid, Z., & Siddiqui, F. (2016). Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. Journal of Prosthodontic Research, 60(1), 12–19. https://doi.org/10.1016/j.jpor.2015.10.001

[12] Ma, R., & Tang, T. (2014). Current strategies to improve the bioactivity of PEEK. International Journal of Molecular Sciences, 15(4), 5426–5445. https://doi.org/10.3390/ijms15045426Lavelle C. (1974). 'Variation in the size of carious and non-carious teeth: a preliminary study'. Journal of the Irish Dental Association, 20(6), pp 253-256.

[13] Rodriguez, F., Cohen, F., Ober, C. K., & Archer, L. (2013). Principles of Polymer Systems. In Principles of Polymer Systems. https://doi.org/10.1201/b12837

[14] Xin, H., Shepherd, D. E. T., & Dearn, K. D. (2013). Strength of poly-ether-ether-ketone: Effects of sterilisation and thermal ageing. Polymer testing, 32(6), 100

[15] Stawarczyk, B., Eichberger, M., Uhrenbacher, J., Wimmer, T., Edelhoff, D., & Schmidlin,

[16] P. R. (2015). Three-unit reinforced polyetheretherketone composite FDPs: Influence of

[17] fabrication method on load-bearing capacity and failure types. Dental Materials Journal, 34(1),7–12. https://doi.org/10.4012/dmj.2013-345

[18] Aldhuwayhi, S.; Alauddin, M.S.; Martin, N., 2022 The Structural Integrity and Fracture Behaviour of Teeth Restored with PEEK and Lithium-Disilicate Glass Ceramic Crowns. Polymers 2022, 14, 1001. https://doi.org/10.3390/polym14051001

[19] Rodríguez, V.; Tobar, C.; López-Suárez, C.; Peláez, J.; Suárez, M.J. 2021 Fracture Load of Metal, Zirconia and Polyetheretherketone Posterior CAD-CAM Milled Fixed Partial Denture Frameworks. Materials 2021, 14, 959. https://doi.org/10.3390/ma14040959

[20] Stawarczyk, B., Eichberger, M., Uhrenbacher, J., Wimmer, T., Edelhoff, D., & Schmidlin,P. R.

(2015). Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dental Materials Journal, 34(1),7–12. https://doi.org/10.4012/dmj.2013-345

[21] Kareem Mohamed Abdelmotaleb., Hesham Katamesh., Reham Saeed El-Basty., 2022EFFECT OF different surface treatment protocols on the retention of posterior peek crowns (a randomized invitro study) egyptian dental journal vol. 68, 589:596, January, 2022

[22] Karimipour-Saryazdi, M., Sadid-Zadeh, R., Givan, D., Burgess, J. O., Ramp, L. C., & Liu, P. R.(2014). Influence of surface treatment of yttrium-stabilized tetragonal zirconium oxides and cement type on crown retention after artificial aging. The Journal of prosthetic dentistry, 111(5), 395-403.

[23] Pilo, R., Folkman, M., Arieli, A., & Levartovsky, S. (2018). Marginal fit and retention strength of zirconia crowns cemented by self-adhesive resin cements. Operative dentistry, 43(2), 151-161.

[24] Lakshmana Bathala., Vaishnavi Majeti., Narendra Rachuri., Nibha Singh., Sirisha Gedela., 2019.The Role of Polyether Ether Ketone (Peek) in Dentistry – A Review Journal of Medicine and Life Vol. 12, Issue 1, January-March 2019, pp. 5–9

[25] Ghodsi, S., Zeighami, S., & Meisami, M. A. (2018). Comparing Retention and Internal Adaptation of Different Implant-Supported, Metal-Free Frameworks. The International journal of prosthodontics, 31(5), 475-477.

[26] Wolfart, M., Lehmann, F., Wolfart, S., & Kern, M. (2007). Durability of the resin bond strength to zirconia ceramic after using different surface conditioning methods. Dental Materials, 23(1), 45-50.

[27] Su, N., Yue, L., Liao, Y., Liu, W., Zhang, H., Li, X., ... & Shen, J. (2015). The effect of various sandblasting conditions on surface changes of dental zirconia and shear bond strength between zirconia core and indirect composite resin. The journal of advanced prosthodontics, 7(3), 214-223.

[28] Sayed, A., Gomaa, Y. F., & Mohsen, S. A. (2017). Effect of Surface Treatment and Type of Resin Cement on Retentive Force of Zirconia Crowns. A Comparative In Vitro Study. EC Dental Science, 13, 245-251.

[29] Uhrenbacher, J., Schmidlin, P. R., Keul, C., Eichberger, M., Roos, M., Gernet, W., & Stawarczyk,B. (2014). The effect of surface modification on the retention strength of polyetheretherketone crowns adhesively bonded to dentin abutments. The Journal of prosthetic dentistry, 112(6), 1489-1497.

[30] Ates, S. M., Caglar, I., & Yesil Duymus, Z. (2018). The effect of different surface pretreatments on the bond strength of veneering resin to polyetheretherketone. Journal of Adhesion Science and Technology, 32(20), 2220-2231.

[31] Ayaka Shirasaki., Satoshi Omori., Chiharu Shin., Mina Takita., Reina Nemoto, and Hiroyuki Miura., (2018) Influence of occlusal and axial tooth reduction on fracture load and fracture mode of polyetheretherketone molar restorations after mechanical cycling Asian Pac J Dent 2018; 18: 29-36.

[32] Georgiev, J., Vlahova, A., Kissov, H., Aleksandrov, S., & Kazakova, R. (2018). Possible.Application of Biohpp in Prosthetic Dentistry: a Literature Review. Journal of IMAB –

Annual Proceeding (Scientific Papers), 24(1),18961898.https://doi.org/10.5272/jimab.2018241.1896

[33] Güngör, M. B., Nemli, S. K., Bal, B. T., Tamam, E., Yılmaz, H., & Aydın, C. (2019). Fracture resistance of monolithic and veneered all-ceramic four-unit posterior fixed dental prostheses afterartificial aging. Journal of oral science, 18-0060.

[34] Tekin, S., Cangül, S., Adıgüzel, Ö., & Değer, Y. (2018). Areas for use of PEEK material in dentistry. International Dental Research, 8(2), 84-92.

[35] Wagner, C., Stock, V., Merk, S., Schmidlin, P. R., Roos, M., Eichberger, M., & Stawarczyk, B.(2018). Retention Load of Telescopic Crowns with Different Taper Angles between Cobalt-Chromium and Polyetheretherketone Made with Three Different Manufacturing Processes Examined by Pull-Off Test. Journal of Prosthodontics, 27(2), 162-168