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FRACTURE RESISTANCE AND STRESS ANALYSIS OF POLYETHER ETHER KETONE VERSUS POLYETHER KETONE KETONE PARTIAL DENTURE FRAMEWORK WITH EXTRA CORONAL ATTACHMENT

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ABSTRACT

Introduction: RPD for class II takes support from teeth and tissue of edentulous span of different compressibility .Prosthetic management concerns not only restoring the missing spans but also protection of remaining teeth and bone along with a healthy soft tissue. Digital technology and recent polymer material such as Polyether ether ketone (PEEK) and poly ether ketone ketone (PEKK) are used for fabrication of RPD with superior esthetics.

The aim of this study: to evaluate the fracture resistance and stress induced by polyether ether ketone (PEEK) versus polyether ketone ketone (PEKK) used in extra coronal attachment of partial denture in Kennedy class II.

Materials and methods: Printed 3D lower resin class II model with detachable dies was used to design two splinted crowns with extra coronal attachment virtually. Each of the study groups :group (A) PEEK and group (B) PEKK had 22 milled splinted crowns with extra coronal attachment and partial denture .load was applied bilaterally and stress analysis and fracture resistance were recorded. Data were collected & statistically analysed to compare both groups by independent t-test, the p-value was considered significant at the level of <0.05.

Results: The two studied groups showed statistically significant where strain induced was reduced in group (B) in compared to group(A)

Conclusion: With in the limitation of this study PEKK material express better distribution of strain & better mechanical properties in compare to PEEK

KEY WORDS: Extra coronal attachment, PEEK, PEKK, fracture resistance, stress analysis

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INTRODUCTION

Posterior teeth loss reduces oral function and affect nutritional status so prosthetic treatment options for partially edentulous patients includes fixed and removable dental prosthesis. [1]

Distal extension bases in class I and II have a problem of support due to the absence of the distal abutment, the difference of compressibility between mucosa and the periodontal ligament thus increasing torque forces on the distal abutment. Rotation of the distal extension base in a tissue ward direction occurs during function under occlusal force which determines the occlusal efficiency of the partial denture. [2 ,3]

One of the reasonable non-invasive solutions for rehabilitation of these cases is conventional RDP following basic principal design to manage the biomechanical challenges of free end saddle cases.[4]

In addition, aesthetics is important as mastication and should be considered while treating patients who are partially edentulous. The aesthetic of the prosthesis should boost the patient's motivation and acceptance.[5,6,7]

An alternative treatment option to full fill aesthetics and biomechanical demands is a combination of fixed and RDPs attached with attachments. A semi-precision extra-coronal attachment used with cast metal cobalt chromium alloy (Co-Cr) framework is the conventional material used which improves retention but not best for aesthetics. [4]

Aesthetic approach in RPD was introduced by using aesthetic material like thermoplastic resin, fiber reinforced composite FRC and Poly aryl ether ketones (PAEK) family as Polyether ether ketone PEEK and Polyether ketone ketone PEKK .[5,8-13]

PEEK provides a lot of mechanical and physical advantages as a high performance, semi-crystalline and thermoplastic. With its relatively stiff backbone that gives excellent high-temperature stability. [25]

PEKK shows excellent physical and mechanical properties, such as melting temperature and compressive strength in comparison to other polymeric materials. In comparison to PEEK (pure and glass-reinforced), PEKK shows better mechanical properties in terms of flexure, tensile, and compressive strength . [14,15]

The digital era using CAD- CAM technology with high accurate 3D scanners and printers enhances the fit and functional components of RPDs and allow the use of new aesthetic materials which would not be applied for RPD fabrication, except digitally like PEEK & PEKK.[16,17,18]

MATERIAL AND METHODS

Sample size

Sample size calculated depending on a previous invitro study (Nabhan MS 2019)[19] as reference. According to this study, the minimally accepted sample size was 22 per group.

Construction of 3D model of lower class II

An educational mandibular Kennedy's class II stone model with the second premolar being the last standing tooth abutment was scanned on desktop scanner (DOF swing scanner, DOFlabs, Seoul, South Korea) to have STL file for designing, modification of virtual model & virtual abutments preparation.

Modification of virtual model &virtual abutments preparation

The abutment lower left canine and lower left first premolar teeth were removed from their sites on the virtual model and prepared separately to give a STL file for the prepared dies that was used later for superimposition of the prepared abutments in their corresponding sockets in previously scanned lower model. Two mm cut back was done virtually

on 3D model for creating mucosa simulation material space and used to design the printed A mucosa key index. fig (1)

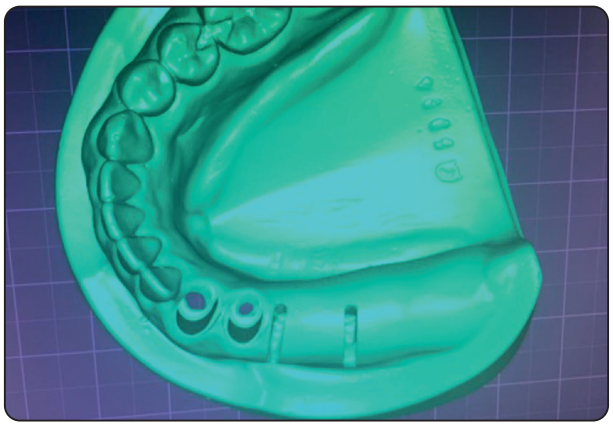

Fig (1): Virtual design of the model showing the sockets of the prepared abutment teeth & periodontal space around abutments roots

Strain gauge virtually preparation on 3D model

Two strain gauge slots were prepared virtually on the 3D model where slot I was prepared 1 mm distal to the socket of the last fist premolar abutment and slot II was prepared 1 cm away from slot I.

Printing of modified virtual model and detachable dies

The two STL files of the modified virtual model and the detachable dies were imported to the additive manufacturing machine (printing type)(Form 2 3D printer, formlabs, Somerville, Massachusetts, United States) to be printed .The mucosa key index was used to inject mucosa simulating material (Gingisil, Soft Endharte Shore a 45,dent-e-con e.k,Germany.) around the roots of the dies and into saddle area.

Splinted crowns and attachments fabrication

The 3D printed mandibular model with the mucosa simulator and prepared abutments mandibular canine and first premolar (detachable dies) were scanned to generate STL file for virtual designing of two fully anatomical splinted crowns on the prepared abutments.

Attachment selection and its criteria

Rod shaped attachment was selected from the bredent digital library (Vario soft 3 mini sv,bredent,Germany) and attached to the distal wall of the first premolar crown in proper position. After modification and virtual designing was done the STL file was imported to the subtractive milling manufacturing machine to fabricate the two splinted crown with rod shaped extra coronal attachment. **fig (2)**

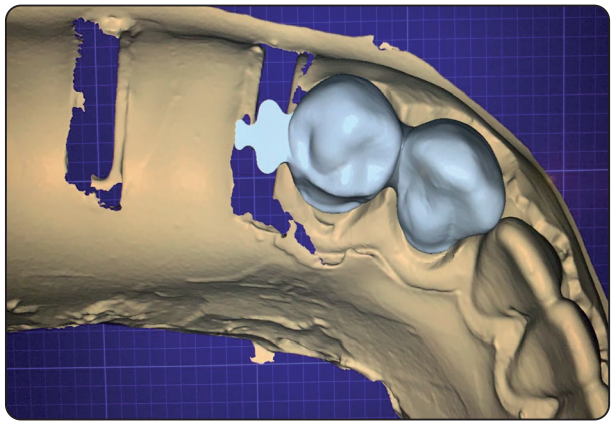

Fig (2): Virtual placement of splinted crown with attachment

Study grouping :

Group A: 22 PEEK splinted crowns with extra coronal attachment

The 22 splinted crowns with attached extra coronal attachment were fabricated by milling of PEEK (BioHPP) blank (Blank size 18,Brecam Biohpp, Bredent, Germany) then their perfect fit to the detachable abutments in their crossponding sockets in the model were checked and then the splinted crowns with extra coronal attachments where cemented with temporary cavex cement (Cavex temporary cement, Cavex Holland BV, Netherland).

Group B: 22 PEKK splinted crowns with extra coronal attachment

Another 22 splinted crowns with attached extra coronal attachment were fabricated by milling PEKK blank (Blank size 18, Brecam PEKK, Bredent, Germany) and their perfect fit were check in same manner as in group A

Partial denture frame work fabrication

After cementation of the two splinted crowns with extra coronal attachment either PEEK or PEKK. The yellow matrix **(vs 3 mini sv REF 430 0733 3)** was attached to the rod shaped extra coronal attachment before scanning for the two models with their parts to produce STL file for designing the partial frameworks.

Partial denture frame work designing

The model was virtually surveyed with blue directional rod installed in the center of the model to assist to determine the desired path of insertion. Lingual plate, minor connectors, occlusal rests on the second premolar and first molar with double akar clasp and finish line were designed and added to the virtual model followed by smoothening of any sharp line angles of the denture framework. **fig (3)** .Then it was converted into STL file for milling RPD frame works for group (A) from PEEK and for group (B) from PEKK. **Fig (4,5)**

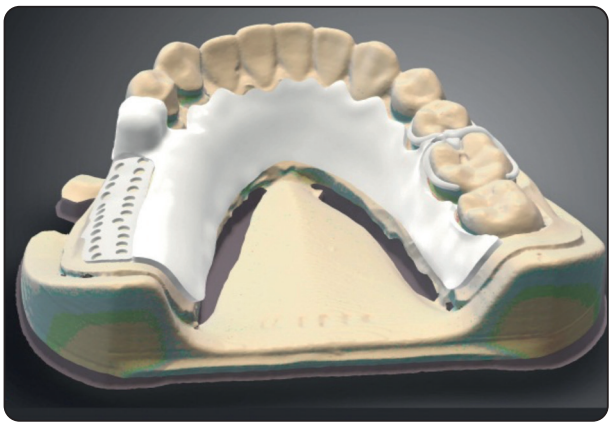

Fig (3) : Partial denture design

Fig (4) : Milled PEKK frame work fit accurately to the printed study model

Fig (5): Milled PEEK framework fit accurately to the printed study model

Setting of artificial acrylic teeth and acrylic denture base curing

The model was duplicated and setting up of acrylic teeth and waxing up was carried out on the duplicate cast. The denture base was processed using heat cured acrylic resin following conventional long polymerization cycle finished and polished in usual manner. The pick-up of the prefabricated matrix housing (the plastic female parts) was done with cold cured acrylic resin material.

Stress analysis and fracture resistance measurements

A-Stress analysis

Strain gauges installation

The strain gauges (Kyowa strain gauges, Tokyo, Japan) with length of 1 mm and nominal resistance 120 ohm were used. Strain gauges were installed in their slots at the distal aspect of the abutment & the residual ridge during the bilateral load application and bonded in their position in the slots of the acrylic model with delicate layer of cyanoacrylate adhesive. Another strain gauge was bonded to the lingual aspect of the minor connector of the double Aker clasp on the contralateral intact side during the bilateral load application. All strain gauges in their slots were placed parallel to the long axes of the abutments. The terminals of the strain gauge wires were inserted into four channels strain meter (Kyowa, kyowa Electronic Instruments Co, Ltd, Tokyo, Japan) to measure the micro strains induced by the applied load.

Load application

Universal testing machine (Lloyd LRX; Lloyd Instruments Ltd., Fareham, UK) was used for applying vertical load bilateral. The model was placed on the lower metal plate of the universal testing machine for calibration 10-60N load were applied five times 10N steps

Bilateral applied load

T-shaped load applicator was used to apply load bilaterally on the occlusal plane between the double Aker on the right side and second premolar region on the left side. The magnitude of the applied load was 100N and was increased from 0-100 N at a constant rate of 0.5mm/min. For each attachment five measurements were made. Recovery period of five minutes was done between the measurements. Once load was completely applied, the data were analyzed using software (Kyowa PCD-300A),tabulated and statistically analyzed. **Fig (6)**

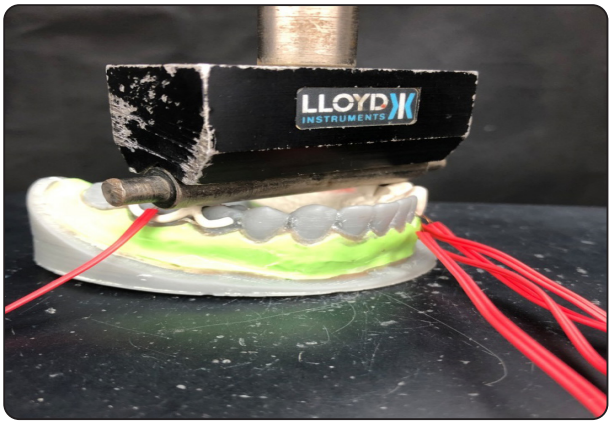

Fig (6): T-shaped load applicator was used to apply load bilaterally

B-Fracture resistance measurement

1-Samples fabrication:

The distal prepared abutment was scanned to give STL file and designing of single crown with attached rod shaped extra coronal attachment from bredent digital library was selected. The STL file was imported to the milling machine to fabricate 44 single crowns with rod shaped attached extra coronal attachment where 22 ones from a PEEK (BioHPP) blank and the other 22 ones from PEKK blank. The produced sampled crowns with attached extra coronal rod shaped attachment were checked for proper fit to the abutment then cemented temporary to the abutment with temporary cements.

The abutment with the cemented single crown with attached rod shaped extra coronal attachment was individually secured by tightening screws on the lower fixed compartment of the universal testing machine.

The vertical loading piston, a vertically movable rod with chesil shape load applicator was mounted after adjusting its tip position contact at the junction area between the attached rod shape extra coronal attachment and the crown. The specimens were loaded until final fracture occurred, and the load at fracture (N) was recorded. The data were collected tabulated and statistically analyzed.

Statistical Analysis

Statistical analysis was performed using statistical package for social sciences, version 21.0(SPSS Inc., Chicago, Illinois, USA).The recorded data followed normal distribution. Data were presented as means and standard deviation (S.D) values. Unpaired t test was used for statistical analysis. P-value <0.05 was considered to be statistically significant. Negative value (-ve) indicate compression strain while positive values (+ve) indicate tensile strain

RESULTS

On applying bilateral load ,the loaded side showed compressive strains in group A (PEEK) where slot 1 mean value was -41.36 with S.D 2.28 and slot 2 mean value was -15.68, with S.D 4.44 and intact side showed mean value -14.55and S.D 10.22 while in the loaded side in group B (PEKK), slot 1 mean value was -31.8 with S.D 2.46 and slot 2 mean value was -131.36 with S.D 2.28 and intact side showed mean value -3.64& S.D 5.81 .On comparing the bilateral compressive strain induced in both groups it was statistically significance as P<0.05 **tab (1)**

Tension strains were showed after bilateral load application in group A (PEEK) where slot 1 mean value was 50.23 with S.D 8.79 , slot 2 mean value was 37.95 with S.D 9.72 and intact side mean value was 955 with S.D 238.95 while in the loaded side in group B (PEKK), slot 1 mean value was 74.7 with S.D 12.39, slot 2 mean value was 65.23 with S.D 1.07 and intact side mean value 53.41 with S.D 5.43. On comparing the bilateral tension strain induced in both groups it was statistically significance as p P<0.05 **tab(3)**

Fracture resistance mean value in group A PEEK showed mean value 840 with S.D 79.81 while group B PEKK showed mean value 699.58 with S.D 66.46 on comparing amount of maximum facture resistance between two groups it showed statically significance as p value <0.05. **tab (3) &fig (7)**

TABLE (1) Bilateral compression load mean and standard deviation in two tested groups

Bilateral	Group I (PEEK)		Group II (PEKK)		(Independent t-test)	
	M	SD	M	SD	MD ± SED	P value
Slot1	-41.36	2.28	-31.82	2.46	9.540 ± 0.7151	<0.0001*
Slot2	-15.68	4.44	-131.36	2.28	115.7 ± 1.064	<0.0001*
Intact side	-14.55	10.22	-3.64	5.81	10.91 ± 2.506	<0.0001*

TABLE (2) Bilateral tension load mean and standard deviation in two group

Bilateral	Group I (PEEK)		Group II (PEKK)		(Independent t-test)	
	M	SD	M	SD	MD ± SED	P value
Slot 1	50.23	8.79	74.77	12.39	24.54 ± 3.239	0.0001*
Slot 2	37.95	9.72	65.23	1.07	27.28 ± 2.085	0.0001*
Intact side	955.00	238.95	53.41	5.43	901.6 ± 50.96	0.0001*

TABLE (3) Comparison between mean and standard deviation of maximum load of fracture resistance in both groups

Group	M	SD	(Independent t-test)	
			MD ± SED	P value
Group I (PEEK)	699.58	66.46	140.4 ± 22.14	<0.0001*
Group II (PEKK)	840.01	79.81		

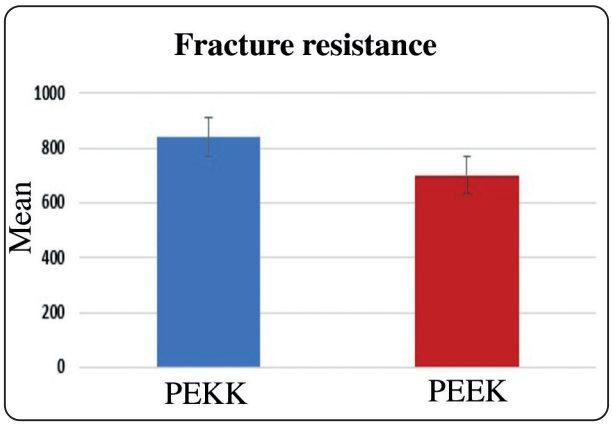

Fig (7): Boxplot representing maximum load of fracture resistance in both groups.

DISCUSSION

Combination of fixed and RDPs attached with attachments was selected as an alternative prosthetic option for the conventional clasp retained RPD to full fill the functional and esthetic demands of the patient.An attachment-retained RDP is considered as an unconventional treatment option of partial edentulism. [4 ,20]

The mandibular class II educational model was scanned to produce 3D model which was used for digital designing &modification of virtual model &virtual abutments preparation so standardization for the two group was done. [21,22]

The models and the abutment teeth were digitally fabricated by additive printing technique that showed higher accuracy of the 3D printing due to the incremental layering process during fabrication that allows for accurate reproduction of all details, adequate compensation of the polymerization shrinkage, and better marginal fit compared to milling.[23,5]

The PEKK and PEEK are the two most well-known esthetic material of the (PAEK) family. The PAEK family are thermoplastic polymers and have been in field since the 1980s and show excellent mechanical properties and chemical resistance. PAEK family show ultra-high performance (superior mechanical performances with chemical resistant) among all thermoplastic composites linked to their processing parameters. [14]

Strain gauge technique is one of the common methods used for dental strain analysis and can overcome many shortcomings of other methods. [24]

Results of the present study are in line with other researches about the characteristics of PEEK material as they reported that PEEK material has favourable biological and mechanical properties particularly for its flexure behaviour which is the chief cause of its advantageous dissemination of stresses. [4,25,26,27]

During bilateral loading, there was statistically significant difference between the two groups where the PEEK attachment showed less micro strains in slot I and at double aker on the intact side than PEKK attachment. On the other hand, the micro strain recorded in slot II were higher for PEEK compared to PEKK. Such results matches with the results reported by Jin Ki-sun lee et al.[28] & Diego et al.[29] that the shock absorbing property of PEEK is limited to the site of its presence. But distant sites received higher stresses when PEEK was used compared to other rigid materials. All the micro strains were compressive in nature. [28,29]

The result of this study with high fracture resistance of PEKK were in line with results of Lee et al[30] where PEKK presents superior biomechanical behaviour compared to metal and fiberglass post-core systems due to lower elastic modulus and flexural strength.[14,30]

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