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A Comparative Evaluation of Stress Distribution, Deformation and Retentive Force of Three Different Partial Denture Framework in Two Removable Partial Denture Designs: A Finite Element Analytical Study

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Abstract:-

- ***Aim:***

The aim of this study is to evaluate and compare stress distribution, deformation and retentive force of three different partial denture framework in two removable partial denture designs.

- ***Materials & Methodology:***

CBCT images of Kennedy's class I & II mandibular arches were converted to STL file. HYPERMESH 10 software was used to convert 3D images into numerical models. Geometric model of the Kennedy's class I & II frameworks were created using ANSYS 18 software and then was inserted in the bone model. Material properties of titanium alloy, acetal resin and PEEK was taken from the standard textbooks. The models were then transferred through the solid works stimulation program for finite element analysis to evaluate stress distribution, retention and deformation forces. A vertical force of 120N was applied on the occlusal surface of the teeth.

- ***Results:***

The stresses induced on the residual ridges in Kennedy's class I for titanium, acetal resin & Peek frame work was 5.08056Mpa, 5.08032Mpa &5.07888Mpa respectively and on primary abutment teeth was 1.75897Mpa, 2.43683Mpa & 2.34344Mpa respectively. The stresses induced on to the class I framework for titanium, acetal resin & PEEK was 30.4465Mpa, 10.2463Mpa &8.28491Mpa respectively. The stresses induced on the residual ridges in Kennedy's class II for titanium, acetal resin & PEEK frame work was 4.50508Mpa, 3.45925Mpa & 3.53304Mpa respectively and on primary abutment was 1.9083Mpa, 2.52222Mpa &2.48319Mpa respectively. The stresses induced on to the class II framework for titanium, acetal resin & PEEK was 28.5811Mpa, 11.0531Mpa & 9.03564Mpa respectively. The retentive force for titanium, acetal resin & PEEK clasps was 1615.9N, 335N &1260.1N respectively in Kennedy's class I framework. The retentive force for titanium, acetal resin & PEEK clasps was 1721.4N, 310.5N & 1155.4N respectively in Kennedy's class II framework. The deformation force for class I titanium, acetal resin &PEEK clasps, was 0.009087mm, 0.00933mm & 0.009355mm respectively. The deformation force for class II titanium, acetal resin & PEEK clasps was0.004304mm, 0.004896mm & 0.004628mm respectively.

- **Conclusion:**

No significant difference between the von mises stress on the residual ridge was observed in Kennedy's class I for all the three frameworks.Von mises stress on residual ridge from titanium framework was slightly higher when compared to acetal resin and PEEK frameworks for Kennedy's class II.Von mises stress on the primary abutment teeth was the highest in Acetal resin framework and the least in titanium framework for both Kennedy's class I & II. Retention force was highest in titanium clasp and least in acetal resin clasp in both Kennedy's class I & II. Deformation was highest in acetal resin clasp and least in titanium clasp in both Kennedy's class I & II.

Keywords: *Removable Partial Denture, Finite Element Analysis, Titanium, Acetal Resin, PEEK, Stress Distribution, Deformation, Retention.*

I. INTRODUCTION

Partial edentulism is a terminology given when one or more but not all-natural teeth are missing in a dental arch. The removable partial denture is still a viable option in prosthetic rehabilitation, especially for distal extension cases. Distal extensions pose a challenge to the clinician due to association of dental and mucosal support. The major concern, is to maintain equal forces on both the residual alveolar ridges and the abutment teeth, and provide enhanced function, comfort and aesthetics to the patient.[1]In order to consider this treatment successful, the quality of removable partial dentures should be biomechanically favourable and the prosthesis should provide optimal patient satisfaction.[2]One of CpTi's properties that has created interest for RPDs is its low modulus of elasticity,

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which allows for larger amounts of retentive undercut than recommended for Co-Cr alloys. This may be advantageous in clinical situations in which aesthetic and periodontal health are priority. With higher retention levels, CpTi framework may become less deformed and fatigued when subjected to repeated stress.[3]The emphasis on physical appearance has increased the demand for aesthetic dental restorations. A major esthetical problem with removable partial dentures is the display of the clasp assemblies. Many methods are used to overcome the aesthetic problem such as etching the clasp arm and coating it with a layer of tooth-colour resin, using lingual retention design or using the proximal undercuts.[4]Polyoxymethylene (POM) also known as acetal resin, an injection-moulded resin has been introduced as an alternative to conventional PMMA. POM is formed by the polymerization of formaldehyde. The homopolymer, polyoxymethylene is a chain of alternating methyl groups linked by an oxygen molecule. It has a relatively high proportional limit with little viscous flow enabling it to behave elastically and be used as a material for clasp construction.[4]Polyetheretherketone (PEEK), a polymer from the group polyaryletherketone (PAEK) which is relatively a new family of high-temperature thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups. In medicine PAEK has been demonstrated to be excellent substitute for titanium in orthopaedic applications and it has been used in dentistry as provisional implant abutment.[4]FEA in the recent years is widely accepted as a non-invasive and excellent tool for studying the biomechanics and the influence of mechanical forces on the biological systems. The finite element method (FEM) is basically a numerical method of analysing stresses and deformation in the structures of any given geometry. The structure is discretized into the so called ‘finite elements’ connected through nodes. The type, arrangement and total number of elements impact the accuracy of the results. The steps followed are generally constructing a finite element model, followed by specifying appropriate material properties, loading and boundary conditions so that the desired settings can be accurately simulated.[7]Hence, the purpose of this study is to evaluate stress distribution, retention and deformation in three different partial denture frameworks in two removable partial denture designs using finite element analysis.

II. MATERIALS & METHODOLOGY

The present study was conducted in the Department of Prosthodontics, The Oxford dental college, Bangalore and finite element analysis was done at Tejvi techno Solution Laboratory, in Bangalore.

a) *Casts depicting Kennedy’s class I and Kennedy’s class II mandibular arches were collected from the department of prosthodontics, The Oxford Dental College.*
b) *A Cone Beam Computed Tomographic scan machine from Oral D diagnostic centre was used for making the C.T scan images of the partially edentulous casts.*
c) *Workstation computer with following configuration: Intel Xeon CPU E5-2609 Processor with 128GB ram @2.40GHz and 4TB hard disc capacity Windows 7 OS (64 bit) Graphic Card-NVIDIA Quadro 4000: Colour monitor 21 was used.*
d) *Computer-aided Designing model of the CBCT scan reproducing and partially edentulous mandible.*

➢ *Software used:-*

- 3-D SLICER for creation of CAD model from CBCT data
- CATIA Version 5.0 for modelling
- HYPERMESH version 12.0 for meshing
- ANSYS version 18.1 for solving

➢ *Construction of Model:*

- *Modelling of Mandibular Kennedy’s Class I and Kennedy’s Class II Edentulous Arch:*

✓ A Cone Beam Computed Tomography (CBCT) of a patients with kennedy’s class I and kennedy’s class II mandibular arches was taken at oral D diagnostics, Bangalore.
✓ The model was then exported in STL format and was converted to a CAD model for further processing and analysis.
✓ HYPERMESH 11 software was used to convert 3D images into numerical models.
✓ Graphic pre-processing software ANSYS version 18.1 was used for creating the geometric configuration.

➢ *Modelling Of Cast Partial Denture Framework:*

- Two models were constructed with three different framework materials.

✓ *Model 1 consists of Kennedy’s class I removable partial denture design. The design included:*

▪ Mesio Occlusal Rest, I Bar Clasp on Left Second Premolar
▪ Mesio Occlusal Rest I Bar Clasp on Right Second Premolar
▪ Lingual Plate Major Connector.

✓ *Model 2 consists of Kennedy’s class II removable partial denture design. The design included :*

▪ Mesio Occlusal Rest, I Bar Clasp on Left Second Premolar
▪ Embrasure Clasp on Right First And Second Molar
▪ Lingual Plate Major Connector.

➢ *Geometric model of acetal resin, titanium alloy and polyetheretherketone (PEEK) framework material were created by using SOLID EDGE version 19 software and then be inserted in the bone model.*

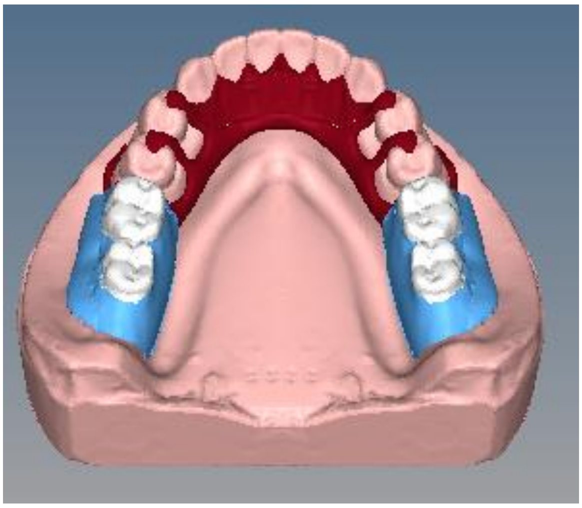


Fig 1 Kennedy's Class I

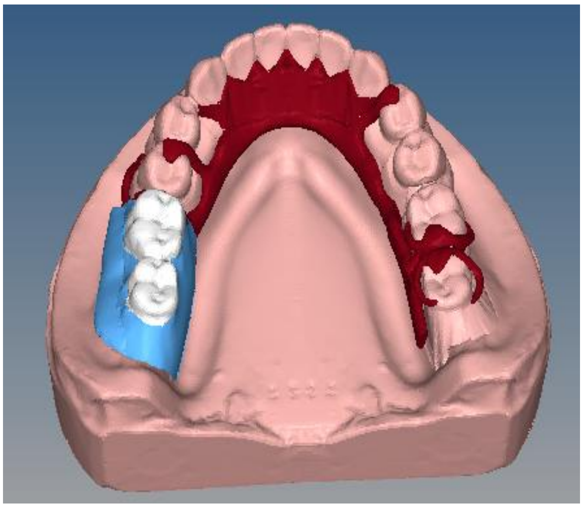


Fig 2 Kennedy's class II

➢ *Preparing of Finite Element Mesh:*

The 3D models were exported to the HyperMesh version 11 software for mesh generation, leading to a virtual geometrical mesh arranged in a 3D manner.

Table 1 Mesh Data-No.of Nodes and Elements

Region	Number of elements	Number of nodes
Model 1	1186430	245532
Model 2	1129608	231523

➢ *Defining the Property of Given Material:*

Table 2 Material Property Assigned to Models

Material	Elastic Modulus (GPa)	Poison's ratio (μ)
Bone	13.7	0.3
Enamel	41.400	0.35
Dentine	18600	0.35
Acetal Resin	2.7	0.2
Peek	3.76	0.38
Titanium alloy	103.43	0.35
Acryllic	68	0.28

III. RESULTS

The stress analysis implemented by ANSYS version 18.1 software provided results that enabled the tracing of stress distribution, retentive and deformation force in the form of color-coded bands. Colour gradients ranging from red to blue with red representing the maximum stress values, which is given in Mega Pascal (Mpa). In the present study, a vertical bite force of 120N that simulates masticatory force was applied.

Table 3 Results

	Class 1			Class 2		
	Acetal resin	Peek	Titanium	Acetal resin	Peek	Titanium
Stress on residual ridge (Mpa)	5.08037	5.07888	5.08056	3.45925	3.53304	4.50508
Stress on primary abutment teeth (Mpa)	2.43687	2.34344	1.75897	2.52222	2.48319	1.9083
Stress on to the framework (Mpa)	10.2463	8.28491	30.4465	11.0531	9.03564	28.5811
Deformation (mm)	0.00933	0.009355	0.009087	0.004896	0.004628	0.004303
Retentive force (N)	335.0	1260.1	1615.9	310.5	1155.4	1721.4

➤ *Stress Distribution in Class I:*

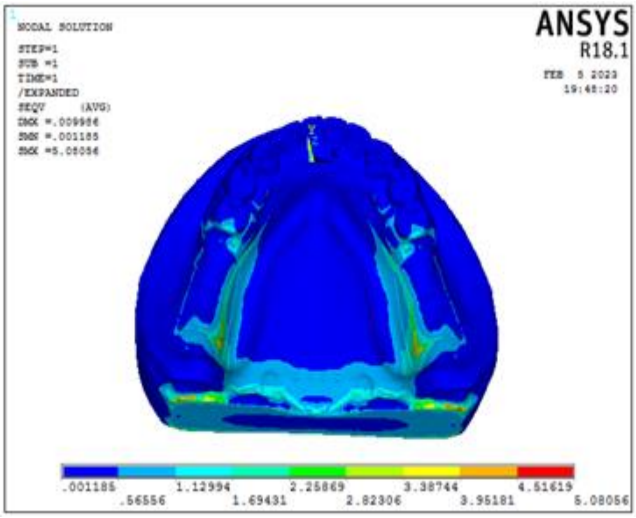


Fig 3 Stress Distribution on residual ridge and primary abutment teeth

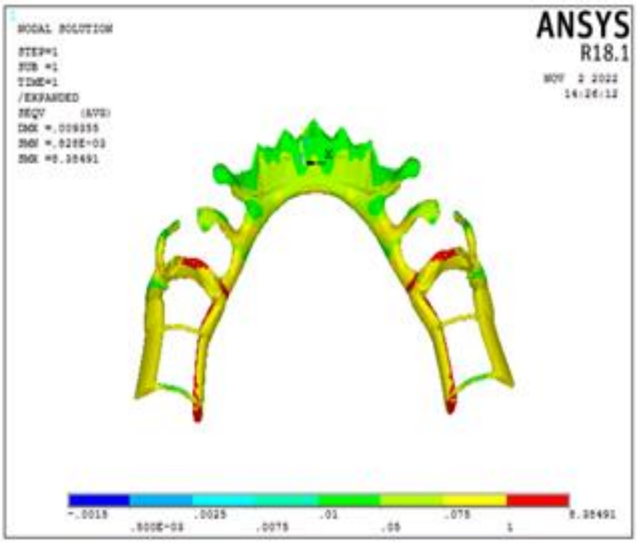
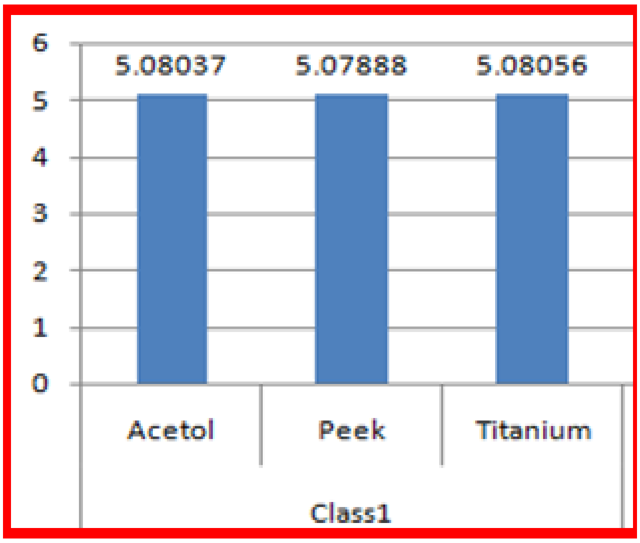
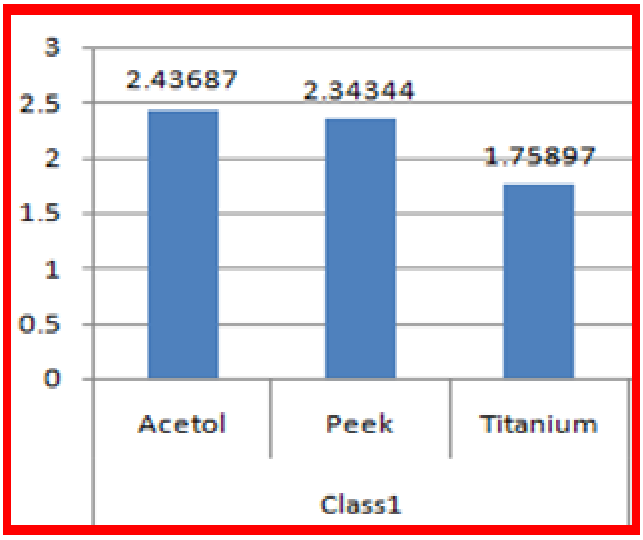


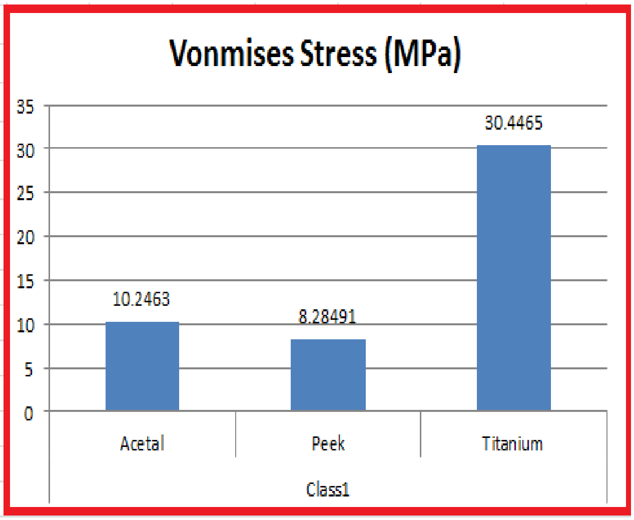
Fig 4 Stress Distribution on the Framework



Graph 1 Comparison of Stress Distribution on Residual Ridge



Graph 2 Comparison of Stress Distribution on Primary Abutment Teeth



Graph 3 Comparison of stress distribution on the frameworks

➤ *Stress Distribution in class II:*

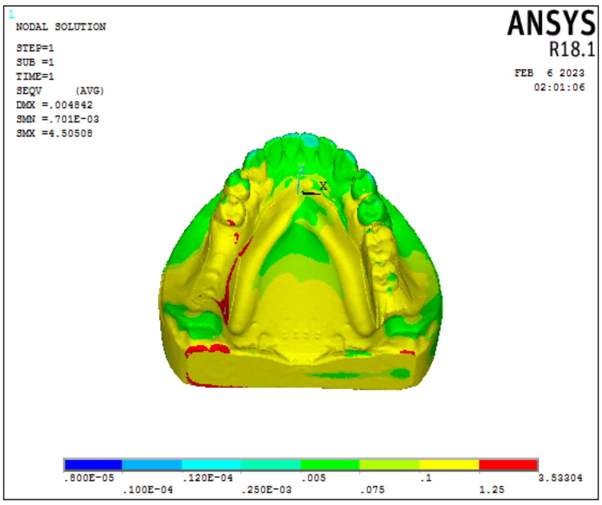


Fig 5 Stress Distribution on Residual Ridge and Primary Abutment Teeth

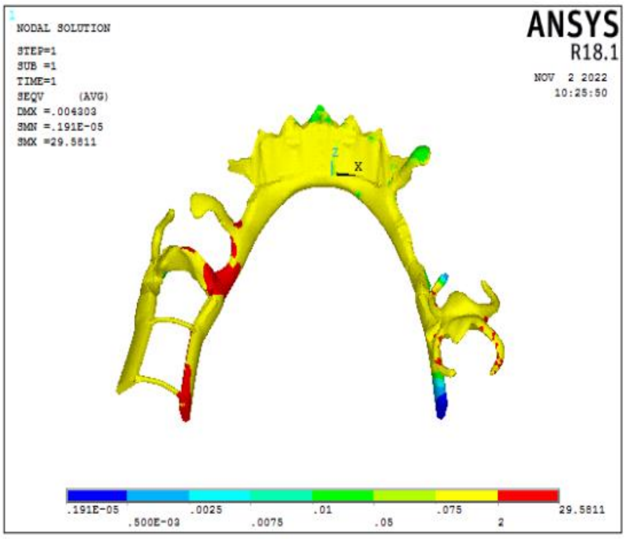
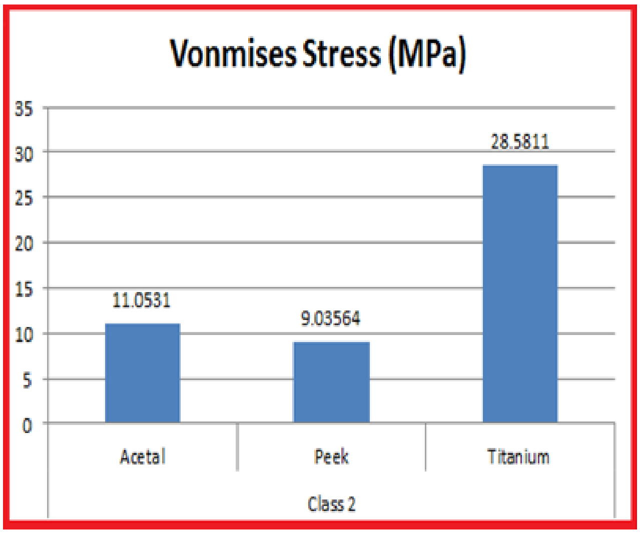
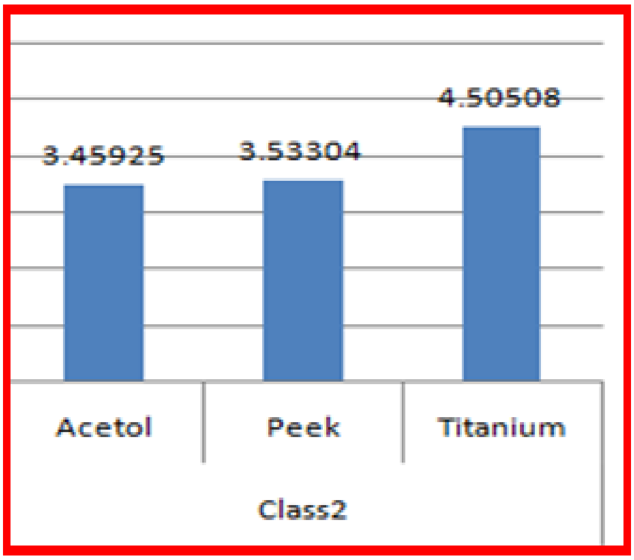


Fig 6 Stress Distribution on the Framework



Graph 6 Comparison of Stress Distribution on the Frameworks



Graph 4 Comparison of Stress Distribution on Residual Ridge

➤ *Deformation in Class I:*

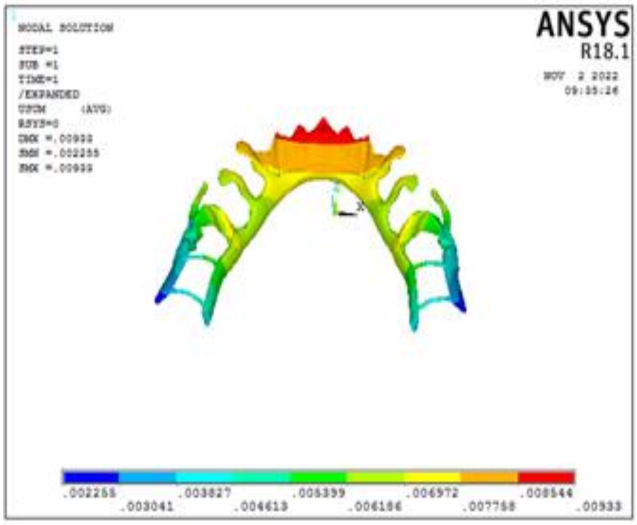
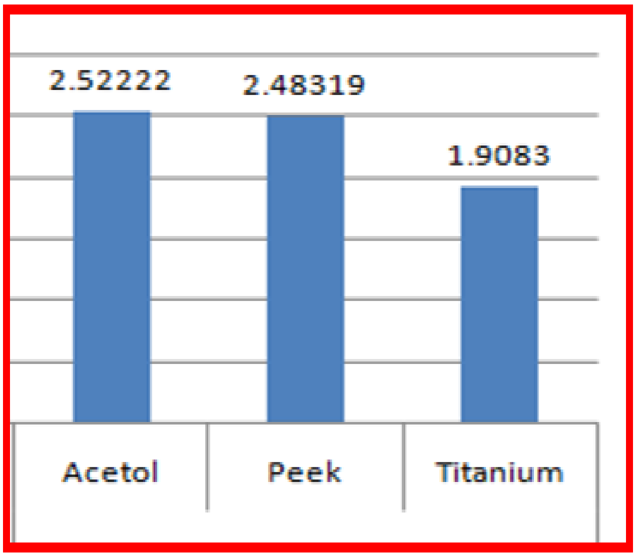
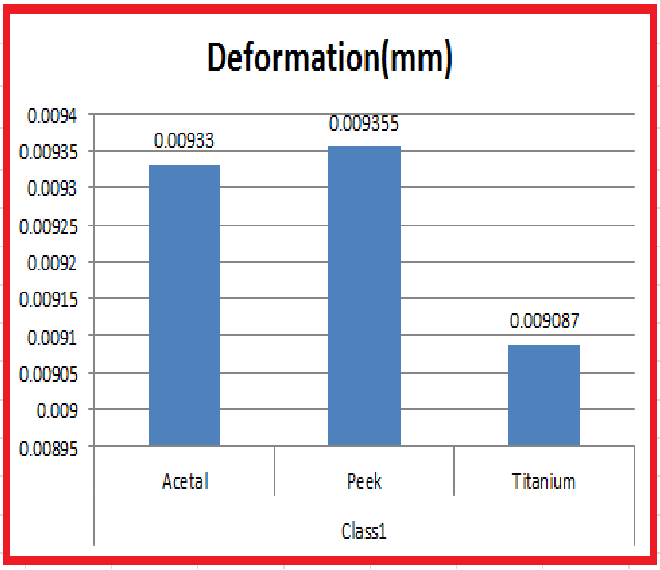


Fig 7 Deformation in Class 1



Graph 5 Comparison of Stress Distribution on Primary Abutment Teeth



Graph 7 Deformation in Class 1

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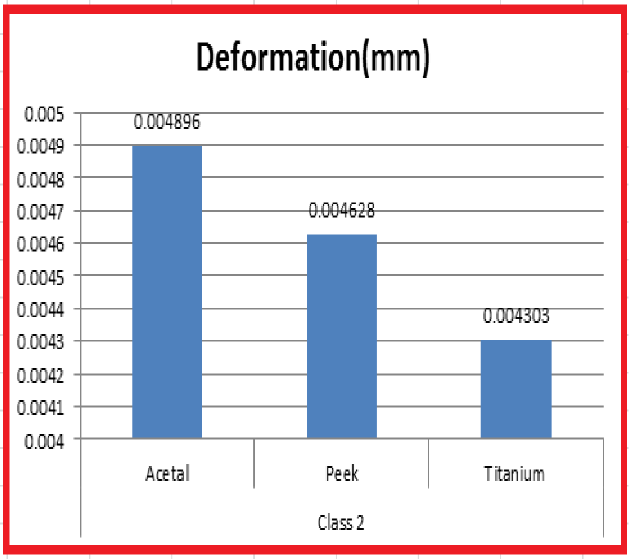
➢ *Deformation in Class II:-*

Fig 8 Deformatin in Class II



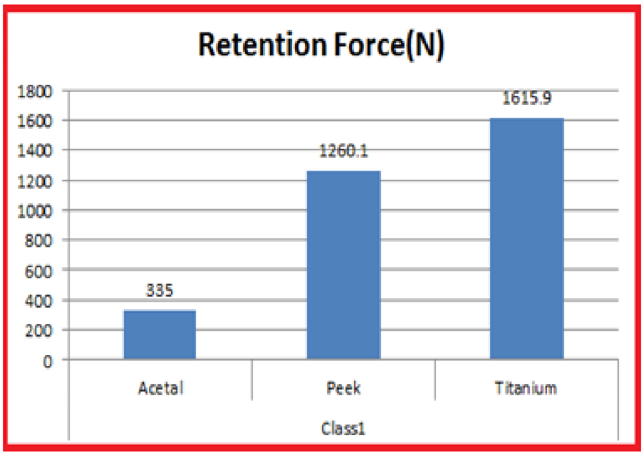
Graph 8 Deformation in Class II

➢ *Retentive Force:*

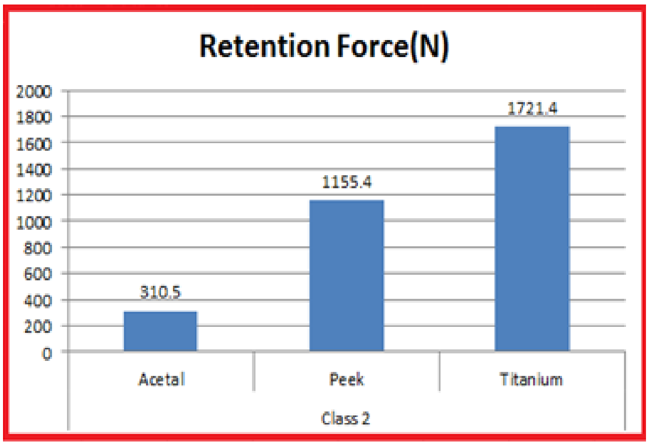
- *Formula for finding the retention force: Yield stress *120/von mises stress:*

Table 4 Material Properties to used to Find Out Retentive Force

Details	Material	Von mises Stress (MPa)	Yield Stress (MPa)
Class1	Acetal	10.2463	28.6
	Peek	8.28491	87
	Titanium	30.4465	410
Class 2	Acetal	11.0531	28.6
	Peek	9.03564	87
	Titanium	28.5811	410



Graph 9 Retentive Force in Class 1



Graph 10 Retentive Force in Class 2

IV. DISCUSSION

The Prosthetic rehabilitation should be able to restore the patient's masticatory function, phonetics and aesthetics because it will significantly affect the quality of life. The difference in viscoelasticity between the edentulous ridges and the periodontal ligament results in masticatory forces turning to become detrimental in tooth tissue supported partial dentures. [9] De van determined that the mucoperiosteum of the residual ridge offers only 0.4% of the support provided by a periodontal ligament, that is ,soft tissues are 250 times more displaceable than are the adjacent teeth. This is particularly important when one considers the masticatory forces placed on an extension base during function.Although initial masticatory forces may be oriented in the long axes of the abutments, differences in tooth and soft tissue support eventually result in non axial loading.[29]In the present study Kennedy's class I partially edentulous situation was considered as it is the most frequently and commonly occurring condition. Kennedy' class II partially edentulous situation was considered as Class II removable partial denture must embody features of both Class I and Class III designs.[29]The master casts were surveyed, the height of contour of the abutment teeth were delineated. Undercuts were determined using the undercut gauges, which was found to be 0.25mm mesio buccal undercut on the primary abutment teeth and the proximal guiding planes were established.Use of a Ti-Ni alloy clasp rather than a wrought wire clasp for distal extension RPDs has 3 advantages. Firstly, soldering, which can reduce the flexibility of a wire, is not necessary and may be beneficial when space for a solder joint is limited or unavailable. Secondly, cast clasps fit better than wrought wire clasps. Finally, some wrought wires are very stiff, whereas the stiffness of Ti-Ni alloys may be more consistent. For these reasons, cast Ti-Ni clasps might be the material of choice in certain clinical situations.[8]This could be attributed to the high stiffness of the titanium alloy. One of the main desirable characteristics of major connectors is that it should be rigid. Rigidity of the major connector fabricated from titanium alloy allows stresses that are applied to any component of the partial denture to be effectively distributed over the entire supporting area, including abutment teeth, underlying bone and soft tissues. Rigid major connectors resist deflection, deformation, and torquing forces that could be transmitted to the abutment teeth and other structures as destructive forces. The major connector is thus the most vital component critically subjected to maximal stress concentration and deflection due to various forces acting on it.[12]Saad swedan et al evaluated radiographically the effect of distal extension removable partial denture either constructed from thermoplastic acetal or vitallium materials on bone height change of abutment teeth. They concluded that thermoplastic acetal mandibular distal extension removable partial denture material was superior to vitallium material regarding the preservation of abutment alveolar bone. [12] Thakral et al. mentioned that acetal resin has a sufficiently high resilience and modulus of elasticity to allow its use as framework for removable partial dentures. Also it is strong, resists fracturing, and does not wear during occlusal forces and consequently will maintain vertical dimension over long periods of time.Zoidis et al in their study concluded that after 1-year clinical follow-up, there was no framework breakage with good clasp retention made from PEEK. Therefore, it could be hypothesized that PEEK would be a viable alternative RPD material for abutments with reduced periodontal support when restoring distal extension cases. The study also stated that, PEEK should be considered as an alternative RDP framework material for patients with taste sensitivity or allergies to conventional Cr-Co frameworks or used as a clasp material with rigid frameworks. [5] Retention is that quality inherent in the dental prosthesis acting to resist the forces of dislodgment along the path of placement. Kotake et al reported that curved Ti-Ni alloy clasps were highly resistant to loss of retention under test conditions engaging 0.25-mm retentive undercuts and stated that this alloy might offer a clinical advantage over conventional alloys used for cast clasps. DongSuk Kim et.al cocluded that cobalt chromium alloy and gold alloy clasps in 0.25mm retentive undercut groups experienced a gradual decrease in retentive force measurements. In contrast Ti-Ni alloy clasps maintained a retentive force of approximately 1.8N and 2.6N for the 0.8mm and 1.4mm clasp groups, respectively.[8]Fitton et al stated that to gain adequate retention from acetal resin clasps, the clasp should have a greater cross-sectional area than a metal clasp. The acetal resin clasp must be thicker and shorter than a standard clasp and engage a deeper undercut to achieve clinically acceptable retention.[21]Frank and Nicholls concluded that 300 to 750 g (2.94 N to 7.35 N) represented an acceptable amount of retention for a bilateral distal extension RPD. The flexibility of a clasp arm affects the retention and the function of an RPD. A study conducted by Azza et.al proved that PEEK resin material group recorded statistically significant higher retentive and fatique resistance mean value than acetal resin material group.Haleem et.al showed that the retentive force values were significantly lower in thermoplastic group compared to metallic group, at denture insertion and at all follow up intervals.[13] Tannous et.al demonstrated that resin clasps of both dimensions had significantly lower retentive force that cobalt chromium clasps.[2]Deformation is the change of form or shape of an object. Retentive clasp arms must be capable of flexing and returning to their original form and should retain an RPD satisfactorily. The tooth should not be unduly stressed or permanently distorted during service.Arda et.al study proved that the mean values of tensile load required to dislodge acetal resin clasps with 1.2mm thickness and with 2.0mm thickness was significantly lower than to dislodge cobalt chromium clasps. The retentive force of cobalt chromium clasps after deformation remained significantly higher than the retentive force of acetal resin clasps.[9]Wu et al. compared deformation of acetyl resin and metal alloy RPD direct retainers after repeated dislodgments over a test die for a simulated 3-year period. They took occlusal and facial digital images before and after cycling and found significantly greater deformations for acetyl resin compared to metal alloy in the occlusal view. Study conducted by Rodrigues stated that, there was no clasp fracture, and the results obtained for the Co-Cr alloys and for pure titanium at both undercut values indicated no permanent deformation even with an increase in the values recorded.[3]Moussa et al; conducted a finite element analysis using different denture base materials and showed that thermoplastic nylon denture base showed the lowest modulus of elasticity (more flexible), consequently, more material deformation and uneven stress distribution was noted and, more load was transmitted to the underlying bone.Acetal Resin RPDs showed stress transmission to the supporting tissues which was in between the titanium and PEEK. Also, there was no significant difference between acetal and titanium regarding von mises stress on the ridge. This may be attributed to presence of some rigidity within the acetal RPD which is greater than PEEK RPD and less than that of the titanium RPD. This is because acetal has a high degree of crystallinity and is known as one of the strongest and stiffest thermoplastic materials.[25]Literature claims that a rigid lingual bar is more desirable for withstanding horizontal stress and restraining excess movements of abutments. Rigid connectors proved to be the most effective in transmitting applied occlusal forces to the contralateral side of the framework.[24]Thus, in the

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present study the stress distribution on the titanium framework was the highest, the stress induced by it on to the bone model and abutment teeth was comparatively less. The stress distribution on the primary abutment teeth was highest in acetal resin and least in titanium. The retention force was highest in titanium clasps and least in acetal resin clasps. The deformation force was the highest in acetal resin clasp and least in titanium clasp.

➢ *Limitation of this Study:*

- Removable partial dentures subjected to a composite of forces arising from three principal fulcrums are not incorporated in the study.
- The resultant force on abutments is usually mesio apical or disto apical with the greatest vector in apical direction is not evaluated in the study.
- FEA technique is based on loads which are applied only at specific point locations.
- Present study used ideal model to fabricate the framework.
- The material properties used in analysis were simplified, which were assumed to be homogenous, isotropic and linearly elastic.
- FEA study is not expected to completely mimic different conditions of the oral environment. In-vivo studies can be further carried out for confirmation of the results.

V. CONCLUSION

➢ *Within the Limitations of the Study, the Following Conclusions Were Drawn:*

- No significant difference between the von mises stress on the residual ridge was observed in Kennedy's class I for all the three frameworks.
- Von mises stress on residual ridge from titanium framework was slightly higher when compared to acetal resin and PEEK frameworks for Kennedy's class II.
- Von mises stress on the primary abutment teeth was the highest in Acetal resin framework and the least in titanium framework for both kennedy's classI & II.
- Von mises stress on to the framework was highest in titanium and least in PEEK framework in both kennedy's class I & II.
- Retention force was highest in titanium clasp and least in acetal resin clasp in both kennedy's class I & II.
- Deformation was highest in acetal resin clasp and least in titanium clasp in both kennedy's class I & II.

Finite element analysis (FEA) being a non linear three dimensional analysis has many feature optimizations and its predictions may be applied to potential removable partial dentures in the coming future.

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