Original Research Paper

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Comparative biomechanical analyses for kennedy's class-I cast partial denture using acrylic denture base with Co-Cr I bar and nylon denture base with nylon retentive clasp: A 3D finite element study.

Abstract:
Introduction: The goal of present PRPD is to optimize esthetics with denture design that ensures minimal invasion to the remaining oral tissues, since the function of an PRPD is affected by physical properties of direct retainers. A comparative 3-D Finite Element (FE) stress analysis for mandibular Kennedy's class-I situation using two different denture base and direct retainer material on distal abutment was done

Method: FE models were developed, with simulated alveolar bone, mucosa, abutments, periodontal ligaments, framework and artificial teeth in the models. The 2 FE models, Model A having PMMA denture base and Co-Cr gingival approaching clasp and Model B having nylon denture base and retentive clasp made up of nylon only were developed. Structural analysis for two designs was carried out using ANSYS FEA software.

Results: During analysisstatic distributed load of 150N over artificial teeth vertically and 45, diagonally was applied. The stresses and deformation produced in assembly were evaluated Structural analysis results were analyzed for various supporting structures. The two designs showed considerable differences in stresses and displacement developed in supporting structures.Cast partial denture with nylon direct retainer and denture base showed greater stresses and displacement than acrylic denture base and Co-Cr clasp on diagonal loading whereas on vertical loading it showed almost similar displacement but slightly greater stresses.

Conclusion: The results of this study suggest the use of nylon as denture base and direct retainer in esthetic region for class I situation as it generate favorable biomechanical stress, being all values are under the physiologic limit.

Key words: removable partial denture, nylon, PMMA, stress analysis, denture base, finite element analysis.

Introduction:

Dental implants are quiet predictable definitive option for distal extension situation but patients generally defer from this treatment owing to the cost, fear of surgery, systemic health and time required to complete the treatment. Therefore, removable partial dentures are still main stay for distal extension partial edentulous cases.

The main advantage of cast partial is its rigidity and support; which is provided by major connector and rest respectively[1]. But on the other hand, visibility of clasps in anterior region may cause cosmetic problem for some patients. In 1955,[2] nylon partial removable dental prosthesis (PRDP) was first introduced which has no metal framework or retentive metal clasp and provides patients with improved esthetics and comfort1. Moreover, it offers advantages for those patients who are allergic to heat-polymerized poly (methyl methacrylate) (PMMA) resin[3]. But the nylon PRDP lacks important elements of the traditional PRDP, in particular, occlusal rests and a rigid framework. Therefore, the reinforcement of a denture base fabricated from a polyamide denture base resin has been recommended.[4]

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A combination of the nylon and traditional PRDP has been reported in clinical reports.[5] and proving to benefit patients in terms of aesthetics and reduced cost, moreover it is reported as mucosa friendly prosthesis. Hence, this research was undertaken to compare biomechanical stress analysis of a combined nylon and traditional PRDPs by using three-dimensional finite element analysis.

Material and Method:

For generating point cloud data to generate quality 3D mesh, a randomly selected cadaveric edentulous mandible was scanned using 3D Laser Kreon KZ 100 scanner. Point cloud data of natural teeth (incisor to first premolar) and selected artificial teeth corresponding to same cadaveric mandible were generated using CBCT. CAD models for various components were generated using ITK Snap, Mesh Lab and Solid Works Premium software. After developing individual components, required assembly was carried out using Solid Works Premium software to assemble, create geometric model and exported in ANSYS FEA software for analysis. Mandibular PRPD framework designed for edentulous area distal to the right first premolar. Each framework included an extension denture saddle, a mesial occlusal rest and proximal plate on right first premolar, a cingulum rest on canine, a major connector as lingual bar.p[1] Ladder pattern of cast partial framework was modeled by giving offset on the surface of denture bearing mucosa transversely and longitudinally. I bar was modeled.[6] Solid model of mandibular body was assumed as cancellous bone, then a uniform offset of 1mm was created to simulate cortical bone. The alveolar socket cavities with respect to all natural teeth present from central incisor to first premolar were created into the mandibular bone. The teeth were then embedded into cavities with 0.35mm periodontal ligament space all around the root surface.[7]

1.5mm offset to the surface of cortical bone was modelled in the edentulous span to simulate mucosa. Artificial teeth were arranged at the occlusal plane level and denture base is constructed till artificial teeth from mucosa. This created Model A (fig 1a). For Model B I-bar was omitted and flexible clasp was created by using offset operation in the region of first premolar in the shape of C-clasp (fig 1b).

These solid geometric models were meshed using3D- 4 nodded tetrahedral elements with the element size up to 500µm using Auto meshing operation8 and a linear structural analysis was performed. All the vital tissues, Co-Cr cast partial frame, acrylic resin, polyamide resin in the study were presumed to be linearly elastic, homogenous and isotropic while the non-linear time-dependent viscoelastic property of mucosa and the sliding, friction phenomenon that usually occur between the denture saddle and the mucosa were not considered in calculations.[9]

The corresponding elastic properties such as E (Young's modulus), and Poisson's ratio (µ) was determined according to literature survey.(table 1)

The mathematical model was verified by computation of the axial displacement corresponding to 10N vertical force to the mandibular first premolar. A displacement of 0.02 mm was computed10. Symmetric boundary conditions were imposed at the mid symphyseal region since only half of the mandible was modeled. On the distal side all the three translations were fixed.

Area of load application is occlusal surfaces of second premolar, first molar and second molar. The vertical static distributed force of 150N was directed vertically in the frontal plane. 11 Second application of static distributed force of 150N at 45 degrees to vertical. This force most nearly simulated the force applied for crushing during mastication.[12]

Linear Stress analysis was performed in ANSYS 14.0 and color contoured diagrams of calculated Von Mises stresses shows the stress distribution. Stress contour plots and deformations were visualized and interpreted for area of interest viz; denture base, clasp, mucosa, cortical bone and distal abutment tooth.

Results:

Von mises stresses and deformation obtained from both models have been summarized in table 2 & 3 respectively:

PRDP and supporting structures complex:

Maximum von mises stresses observed greater in model B on both vertical and diagonal loading. Maximum stresses are observed in cast partial framework in both models in both loading conditions, being made up of Co-Cr. On diagonal loading, more stress was observed in buccal direction i.e. buccal cortical bone, abutment tooth in buccal direction. (fig.2a-d)

Maximum deformation observed in both assemblies are almost similar on vertical loading, though on diagonal loading it is more in Model B. Deformation pattern in both models follow same deformation patterns, being minimum near abutments and gradually increasing to maximum at distal end of denture.(fig. 2e-h)

Abutment teeth:

Maximum von mises stresses observed in abutment teeth of both models were significantly greater in model B on vertical loading and slightly greater in model A on diagonal loading i.e indicating effectiveness of flexible c-clasp. Maximum stresses were transferred to the abutment teeth were along the long axis of the tooth in both models.(fig. 3a-d)

Maximum deformation observed in abutment teeth are observed greater in model B on both vertical and diagonal loading. Maximum deformation was greater at the disto-occlusal surface and decreasing.

Residual ridge mucosa:

Maximum von mises stresses observed were greater in model A on both loading conditions. Stress pattern is similar in both models, being minimum near abutment region and maximum at the distal end.

Maximum deformation observed in residual ridge mucosa were observed in distal end., on both vertical and diagonal loading. On vertical loading, similar deformation pattern observed. On diagonal loading, greater deformation is observed in model B.(fig.4a-d)

Bone:

Maximum von mises stresses observed were greater in model A on both loading conditions. Maximum stresses observed adjacent to disto-cervical aspect of distal abutment and buccal cortical plate adjacent to distal most abutment on diagonal loading.(fig 5a-d)

Maximum deformation observed in bone were observed in model B were greater than model A on both loading conditions. Greatest deformation observed in model A on vertical loading is in the middle edentulous region and on diagonal loading maximum deformation observed adjacent to distal abutment.

Maximum deformation observed in bone were observed in model B were greater than model A on both loading conditions. Greatest deformation observed in model A on vertical loading is in the middle edentulous region and on diagonal loading maximum deformation observed adjacent to distal abutment.

Discussion:

In prosthetic treatment, the structural design of PRDPs is critical for preventing distortion of the prosthesis, protecting abutment teeth and residual ridges and for good masticatory performance.

In the process of masticating a bolus of food, the forces of mastication are transmitted to the teeth and supporting structures. The capacity of teeth and supporting structures to resist these forces will result in either beneficial, physiological stimulation, or harmful, pathologic trauma. Therefore, it is imperative that the stresses exerted upon the various components of the masticatory system during masticatory and non-masticatory movements be confined well within the physiologic limits of tolerance.13 Maximumvon mises stress observed in model B assembly is greater than model A owing to more retention of stresses by nylon denture base and further lesser transmission to supporting structures in comparison to model A.

The free-end denture base appliance is usually regarded as having two sources of support-one from selected abutment teeth and one from the denture base. While the tooth component of this dual support for the extension partial denture is the lesser, it nevertheless is most important. This is particularly true in the lower Kennedy's class-I partial denture, where the supporting ridge form may be extremely poor.[14]

A number of researches have been carried out in past to study the load transfer characteristics of various partial denture designs using mechanical means, 2 or 3D photoelasticity, pressure gauge. The most desirable criterion was the way these designs transmit the stresses to supporting structures. It is always preferred to transmit masticatory load by an abutment tooth rather than by an extension base because it is provided with proprioceptive innervations plus periodontal ligament is arranged in way to best withstand occlusal forces in the long axis. This criterion has been fulfilled by model A and B, though slightly higher in model B owing to greater stresses in nylon denture base but all stresses transferred along long axis of tooth; which is in accordance to study conducted by Cecconi et al, Kratochvil15,16 This is also in accordance to Thompson et al who reported the most favorable force to abutments came with a mesial rest and either a wrought wire or an I-bar retentive clasp.[17]

Vertical transmission of occlusal forces has been observed in both models through cortical and cancellous bone during vertical loading (act of swallow); owing to the presence of conventional cast partial framework in both designs. This indicates both models are favorable for bone remodeling and alveolar bone preservation.

Nylon clasp is resulting in more deformation and stresses in abutment tooth, except lesser maximum stress under diagonal loading. Hence, it's not a very useful retentive component, and Jean C. Wu18 in an in-vitro study has also reported greater deformation with acetyl resin compared with metal alloy direct retainers after three years of simulated use.

The role the subjacent soft tissues play in the success or failure of removable partial dentures is unique and interesting. Soft tissue beneath denture bases plays both a mechanical and a physiological function. Stresses and deformation on residual ridge mucosa, both are found slightly lesser in nylon cast partial denture than PMMA cast partial denture except deformation on diagonal loading. All designs for both kind of loading conditions showed maximum deformation in areafarthest from the abutment tooth, which is in accordance with Lytle[19]. Moreover, as suggested by Thompson et al, that thickness of the tissues covering ridges undoubtedly affects the amount of denture movement and will be an important factor in the direction of forces transmitted to the supporting structures. Hence, decision on choice of prosthesis can vary on clinical situation.

Design differences had a relatively weak influence on the stress in the mucosa; this suggested that the material properties of the two models played the major role.

The deformation of the mucosa recorded in the calculations were less than 120 µm, which were all within the range of physiological intrusion with the maximum of approximately 0.5 mm under 4 N of vertical force 20 In this context, it is also suggested that the displacements and stresses created by the loading conditions of the study were smaller than the critical stress that can cause a detrimental effect on the periodontal tissues and the bone. However, since vertical or horizontal saddle displacements could lead to excessive stress in the oral mucosa and the supporting abutment teeth, constructing the PRPD to prevent such movements under occlusal loads might be more important than avoiding pivoting.[21]

Structural limitations of the model were uniformity of the thickness of the residual ridge mucosa and lack of bone. Moreover, considering bilateral symmetry, only right half of mandible was modeled.

Table1: Material properties:

Structure	Elastic modulus Mpa	Poisson's ratio y
Dentin	18,000	0.31
Cancellous bone	1370	0.30
Cortical bone	1,37,00	0.30
Periodontal ligament	69	0.45
Mucosa	10	0.3
Acrylic	1960	0.3
Acrylic teeth	2940	0.3
Co-Cr	2,00,000	0.3
Polyamide(Nylon)	1500	0.42

Table 2:Displacement of components of assembly of traditional and nylon cast partial denture underdifferent loading conditions

Load Condition / Components/ Assembly	Deformation (microns)			
	Vertical loading (PMMA)	Vertical loading (Nylon)	Diagonal loading(PMMA)	Diagonal loading(Nylon)
Overall assembly	42.596	41.88	138.89	146.12
Abutment tooth	11.665	12.238	37.923	39.061
Cortical bone	8.5	8.9291	37.923	39.061
Mucosa	40.69	40.137	118.52	122.15
Denture	42.59	41.88	138.89	146.16

Table 3: Maximum stresses in components of assembly of traditional and nylon cast partial denture underdifferent loading conditions

Load Condition / Components / Assembly	Maximum Stress (MPa)			
	Vertical loading(PMMA)	Vertical loading(Nylon)	Diagonal loading(PMMA)	Diagonal loading(Nylon)
Overall assembly	76.498	79.498	114.63	129.18
Abutment tooth	9.608	12.471	26.031	25.587
Cortical bone	15.667	14.651	50.493	40.818
Mucosa	0.301	0.279	0.77508	0.5
Denture base	9.608	12.471	22.616	24.153

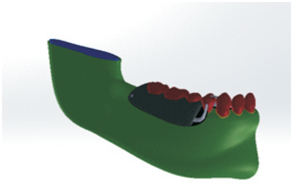
Fig 1: a) mode

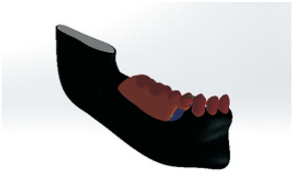
Fig 1:b)model B

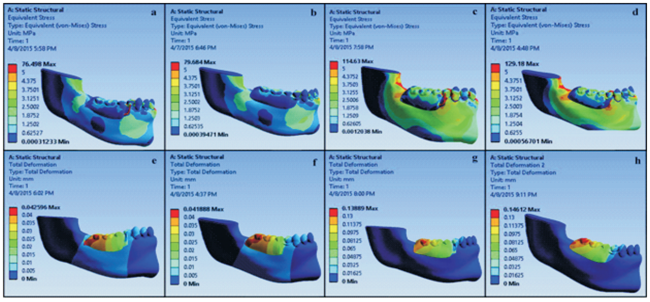

Figure 2a. Acrylic PRDP stresses on vertical loading, figure2b. Nylon PRDP stresses on vertical loading, figure2c. Acrylic PRDP stresses on diagonal loading, figure2d. Nylon PRDP stresses on diagonal loading, figure2e. Acrylic PRDP total deformation on vertical loading, figure2f. Nylon PRDP total deformation on vertical loading, figure2g. Acrylic PRDP total deformation on diagonal loading, figure2h. Nylon PRDP total deformation on diagonal loading

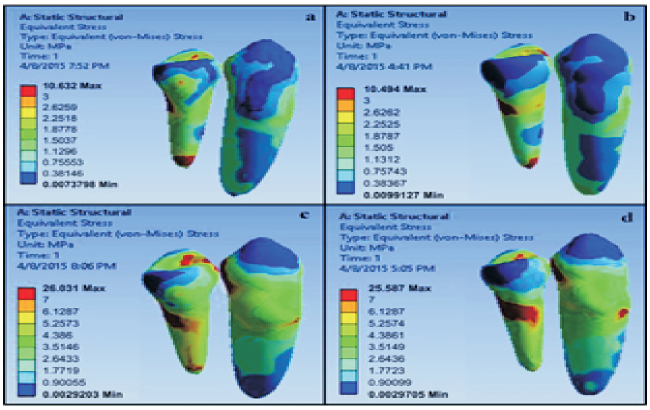

Figure3a. Acrylic PRDP abutment teeth stresses on vertical loading, figure3b. Acrylic PRDP abutment teeth stresses on diagonal loading, figure3c. Nylon PRDP abutment teeth stresses on vertical loading, figure3d. Nylon PRDP abutment teeth stresses on diagonal loading.

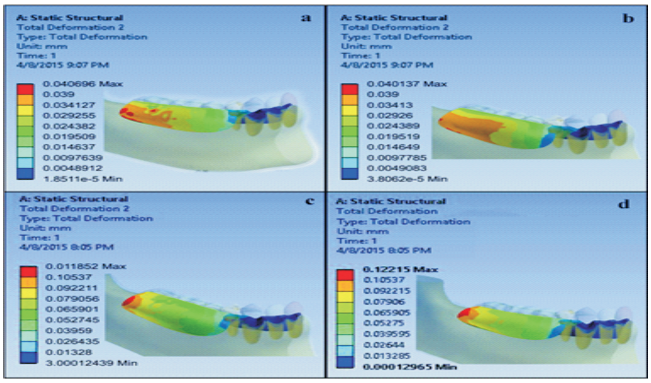

fig 4aAcrylic PRDP mucosa displacement on vertical loading, figure4b.Nylon PRDP mucosa displacement on vertical loading, figure4c.Acrylic PRDP mucosa displacement on diagonal loading, figure4d.Nylon PRDP mucosa displacement on diagonal loading,

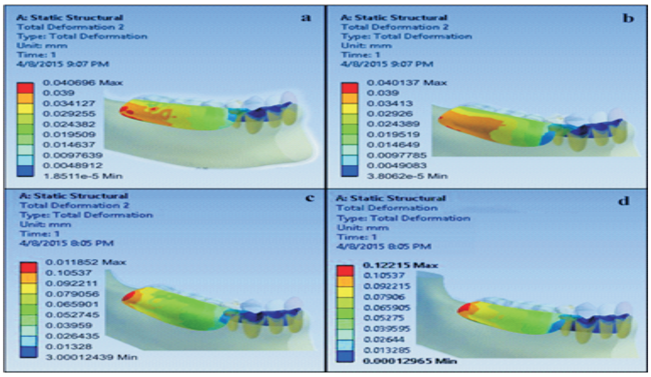

Figure5a. Acrylic PRDP cortical bone stresses on vertical loading. Figure5b:.Acrylic PRDP cortical bone stresses on diagonal loading. Figure5c. Nylon PRDP cortical bone on vertical loading. Figure5d. Nylon PRDP cortical bone on diagonal loading.

Conclusion:

The influence of denture base and clasp material for kennedy's class-I PRPD framework and stress distribution in and around supporting structures was investigated. Within the scope of this study following conclusion can be made:

Nylon cast partial dentures transmits less stresses to supporting structures.

·Nylon cast partial denture has showed more overall deformation in comparison to PMMA cast partial denture, but its well within physiological limit.

·Nylon cast partial denture also transmits occlusal forces along long axis of abutment teeth.

Flexible clasp is slightly less promising retentive component than I-bar during diagonal loading.

Results in this study suggest the possibility of an easy and inexpensive way to improve the esthetics for conventional PRDP by replacing the anterior retentive clasp with nylon clasps, stresses and deformation results are well within physiologic limit. But this computer-based analysis needs clinical studies to prove the results.

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