ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

A Comparative Finite Element Analysis of the Effect of Dynamic Forces on Narrow and Wide Implants in Kennedy's Class 1 Mandibular Implant Supported Cast Partial Denture

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Publication Date: 2026/08/31

Abstract:

- ***Background:***

Implant-assisted removable partial dentures (IARPDs) have emerged as a predictable treatment option for restoring mandibular Kennedy Class I distal extension edentulism by improving prosthesis support, stability, and load distribution. Among the factors influencing their biomechanical performance, implant diameter plays a crucial role in stress transmission to the surrounding bone and prosthetic components. This study evaluated the biomechanical behaviour of narrow and wide diameter implants supporting mandibular implant-assisted distal extension cast partial dentures under dynamic loading conditions using three-dimensional finite element analysis (FEA).

- ***Materials and Methods:***

Two three-dimensional finite element models of mandibular Kennedy Class I arches restored with implant-assisted cast partial dentures were constructed. Model 1 incorporated narrow diameter implants (3.5 × 11.5 mm), whereas Model 2 incorporated wide diameter implants (5.0 × 10 mm). Both models were standardized with identical prosthesis design, attachment system, material properties, and loading conditions. Dynamic cyclic loading of 125,000 cycles was simulated using vertical (150 N) and oblique (100 N) occlusal forces. Maximum prosthesis displacement and von Mises stress distribution in the implant, peri-implant bone, prosthetic framework, denture base, artificial teeth, and abutment teeth were analysed.

- ***Results:***

The narrow implant model demonstrated lower prosthesis displacement (0.16279 mm) than the wide implant model (0.25882 mm). The overall maximum von Mises stress was also lower in the narrow implant model (290.49 MPa) compared with the wide implant model (310.19 MPa). Stress concentrations within cortical and cancellous bone were reduced around narrow diameter implants, while the wide implant model exhibited greater stress transfer to the prosthetic components.

- ***Conclusion:***

Within the limitations of this finite element study, narrow diameter implants demonstrated more favorable biomechanical behaviour by reducing prosthesis displacement and promoting balanced stress distribution under dynamic loading conditions. These findings suggest that narrow diameter implants may be a viable option for implant-assisted distal extension removable partial dentures when appropriate case selection and prosthetic design are employed.

Keywords: *Finite Element Analysis; Implant-Assisted Removable Partial Denture; Kennedy Class I; Narrow Diameter Implant; Wide Diameter Implant; Dynamic Loading.*

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

How to Cite: Dr. Devayani D. K.; Dr. Ponnanna A. A.; Dr. Smitha Gujjar B.; Dr. Ranganatha Rao K. Jingade; Dr. Prathima K.; Dr. Akshitha H. M. (2026) A Comparative Finite Element Analysis of the Effect of Dynamic Forces on Narrow and Wide Implants in Kennedy's Class 1 Mandibular Implant Supported Cast Partial Denture. *International Journal of Innovative Science and Research Technology*, 11(8), 2174-2182. https://doi.org/10.38124/ijisrt/26aug701

I. INTRODUCTION

Partial edentulism is a common clinical condition that adversely affects mastication, speech, aesthetics, and the overall quality of life of affected individuals. Conventional removable partial dentures (RPDs) remain one of the most frequently used treatment modalities for the rehabilitation of partially edentulous patients because they are economical, minimally invasive, and suitable for patients with anatomical or financial limitations that preclude fixed prosthetic rehabilitation. However, distal extension removable partial dentures, particularly those classified as Kennedy Class I, present unique biomechanical challenges due to the absence of posterior abutment teeth. Consequently, the prosthesis derives support from both the remaining natural teeth and the resilient edentulous ridge mucosa, resulting in differential movement during functional loading and increased stress on the supporting structures (1–4).

The rotational movement of conventional distal extension RPDs around the terminal abutments may lead to excessive loading of the periodontal ligament, accelerated residual ridge resorption, clasp fatigue, prosthesis instability, and reduced patient comfort. Long-term use of conventional distal extension prostheses has also been associated with adverse biological changes, including progressive bone loss and the development of combination syndrome in patients opposing maxillary complete dentures (5–8). Therefore, improving the support and stability of distal extension removable partial dentures remains an important objective in contemporary prosthodontic practice.

The introduction of dental implants has significantly expanded the treatment options available for partially edentulous patients. Implant-assisted removable partial dentures (IARPDs) represent a conservative treatment approach in which strategically placed implants beneath the distal extension base provide additional support and retention without requiring a completely implant-supported prosthesis. The incorporation of posterior implants effectively converts a Kennedy Class I situation into a biomechanically more favourable condition by reducing denture base rotation, minimizing stress on the abutment teeth, and improving prosthesis stability during mastication (9–12).

Several clinical studies have demonstrated that implant-assisted removable partial dentures improve patient satisfaction, masticatory efficiency, retention, and oral health-related quality of life when compared with conventional removable partial dentures (9–11). Furthermore, the use of posterior implant support has been shown to reduce residual ridge loading while promoting a more favorable distribution of occlusal forces between the implants, abutment teeth, and supporting bone (10–13). As a result, implant-assisted removable partial dentures have become an increasingly accepted treatment modality for distal extension cases, particularly in situations where fixed implant-supported restorations are not feasible.

Although implant-assisted removable partial dentures have demonstrated favorable clinical outcomes, several biomechanical factors continue to influence their long-term success. Implant position, implant diameter, implant length, attachment design, framework configuration, and the direction of occlusal loading all contribute to stress transmission within the implant-prosthesis complex (14–18). Among these variables, implant diameter has received particular attention because it directly influences the implant–bone contact area, primary stability, and the manner in which functional forces are transferred to the surrounding cortical and cancellous bone.

Wide diameter implants generally provide greater surface area and increased mechanical stability; however, they may also alter stress transmission patterns because of their increased rigidity. Conversely, narrow diameter implants demonstrate greater flexibility and may distribute occlusal loads more uniformly within the supporting bone under certain loading conditions. Previous finite element analyses have reported inconsistent findings regarding the biomechanical advantages of different implant diameters, with some investigations demonstrating reduced peri-implant stress around wider implants, whereas others have reported more favorable stress distribution with narrow diameter implants depending on implant position, loading direction, and prosthesis design (15–20). These conflicting observations indicate that the influence of implant diameter on stress distribution remains incompletely understood.

Finite element analysis (FEA) has become an indispensable research tool for evaluating the biomechanical behaviour of implant-supported prostheses. It enables three-dimensional simulation of complex anatomical structures while allowing quantitative assessment of stress distribution, strain patterns, and prosthesis displacement under standardized loading conditions that cannot be measured directly in vivo. Compared with laboratory testing and clinical investigations, finite element analysis provides reproducible results while eliminating biological variability and permitting independent evaluation of individual design variables (18–21).

Although numerous finite element studies have investigated implant-assisted removable partial dentures, comparatively few have specifically evaluated the influence of implant diameter under dynamic cyclic loading conditions that more closely simulate physiological mastication. Most previous investigations have focused on static loading conditions or evaluated only isolated implant parameters, leaving limited evidence regarding the

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

comparative biomechanical performance of narrow and wide diameter implants supporting mandibular Kennedy Class I implant-assisted removable partial dentures.

Therefore, the present study aimed to compare the stress distribution and prosthesis displacement associated with narrow diameter and wide diameter implants supporting mandibular implant-assisted distal extension cast partial dentures under dynamic loading conditions using three-dimensional finite element analysis. The null hypothesis was that implant diameter would not significantly influence prosthesis displacement or the distribution of von Mises stress within the implant-assisted removable partial denture system.

II. MATERIALS AND METHODOLOGY

This in vitro computational study was conducted using three-dimensional finite element analysis (FEA) to evaluate the biomechanical behaviour of narrow and wide diameter implants supporting mandibular implant-assisted distal extension cast partial dentures under dynamic loading conditions.

➢ *Construction of Three-Dimensional Models*

Two three-dimensional finite element models representing mandibular Kennedy Class I partially edentulous arches were developed using computer-aided design (CAD) software. Both models were standardized with identical anatomical dimensions, prosthesis design, framework configuration, attachment system, loading conditions, and material properties. Implant diameter was the only variable investigated.

- Model 1: Narrow diameter implant (3.5 × 11.5 mm)
- Model 2: Wide diameter implant (5.0 × 10 mm)

Each model consisted of cortical bone, cancellous bone, remaining mandibular teeth, periodontal ligament, cobalt–chromium cast partial denture framework, acrylic denture base, acrylic resin artificial teeth, locator attachment system, and bilateral implants placed in the mandibular second molar region.

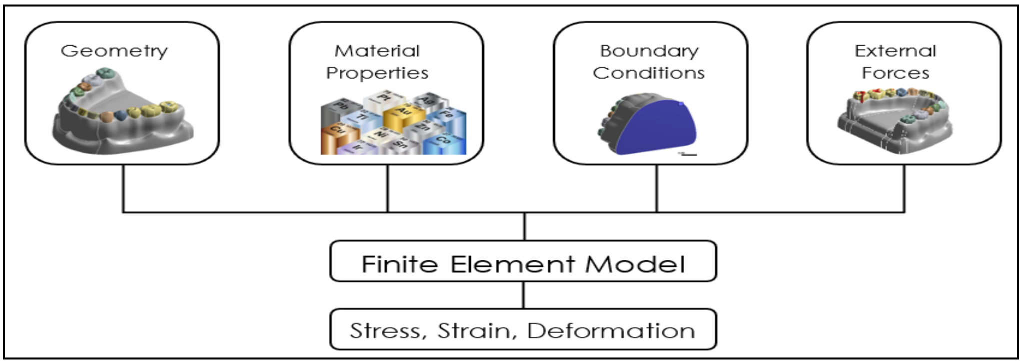


Fig 1 Workflow of the Finite Element Model Generation and Analysis.

➢ *Prosthesis Design*

The cast partial denture framework was designed according to conventional prosthodontic principles. The framework incorporated a lingual bar major connector, mesial occlusal rests on the first premolars, distal guide planes, proximal plates, and RPI clasp assemblies to provide adequate support, stability, and retention.

Locator attachment systems were incorporated over the bilateral implants to convert the distal extension removable partial denture into an implant-assisted removable partial denture. The prosthetic design was maintained identical in both models to ensure that implant diameter remained the only independent variable.

➢ *Implant Placement*

Virtual implants were positioned bilaterally in the mandibular second molar regions beneath the distal extension denture base.

- *Two Separate Finite Element Models were Generated:*

✓ Model 1: Narrow diameter implants measuring 3.5 mm × 11.5 mm

✓ Model 2: Wide diameter implants measuring 5.0 mm × 10 mm

Locator abutments were connected to both implant models to standardize the attachment mechanism and ensure comparable biomechanical conditions.

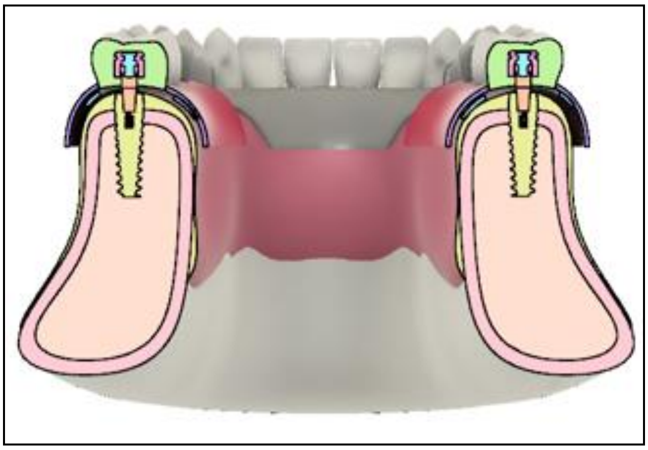


Fig 2 Three-Dimensional Model Showing Narrow Diameter Implants with Locator Attachments.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

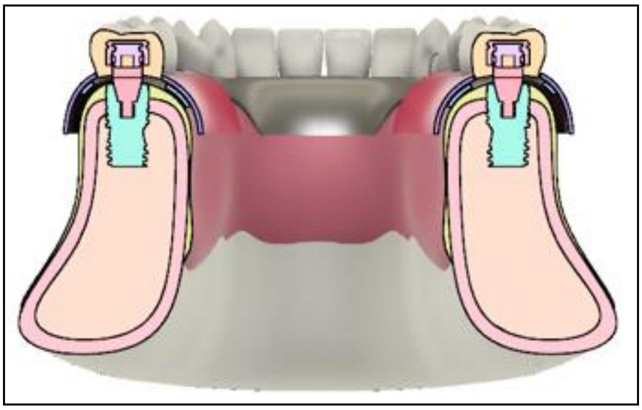


Fig 3 Three-Dimensional Model Showing Wide Diameter Implants with Locator Attachments.

➢ *Finite Element Mesh Generation*

The completed CAD assemblies were imported into HyperMesh 2019, where three-dimensional tetrahedral meshing was performed. The generated finite element mesh consisted of approximately 2.18 million elements and 534,155 nodes, providing adequate geometric accuracy for biomechanical analysis.

The finalized mesh models were exported to ANSYS Workbench 2019 for stress analysis.

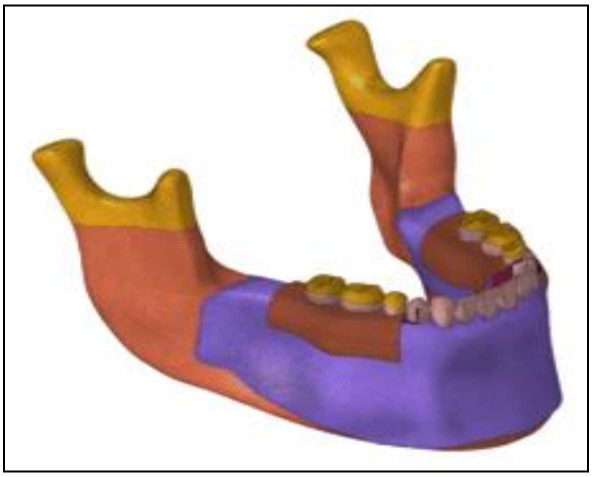


Fig 4 Finite Element Mesh Generated for the Mandibular Implant-Assisted Removable Partial Denture Model.

➢ *Material Properties*

All components of the finite element models were considered isotropic, homogeneous, and linearly elastic. Material properties including Young's modulus and Poisson's ratio were assigned based on previously published finite element studies. Complete osseointegration between the implants and surrounding bone was assumed.

- *The Material Properties Assigned Included:*

Table 1 Mechanical Properties of Materials used in the Finite Element Model Showing Elastic Modulus and Poisson’s Ratio of Biological Tissues and Prosthetic Components.

Sl. No	Parts	Elastic modulus (MPa)	Poisson's ratio
1	PDL	50	0.45
2	Tooth	20,000	0.30
2	Cortical bone	13700	0.30
3	Cancellous bone	1370	0.30
4	Gingiva	3	0.45
5	Acrylic artificial teeth	2940	0.30
6	Titanium Ti6Al4V (implant)	135000	0.30
7	Titanium Grade 4(Locator attachment)	114000	0.30
8	Acrylic resin (denture base)	2940	0.30
9	Nylon (plastic attachment)	2550	0.30
10	Cobalt- chromium framework	218000	0.33

➢ *Boundary Conditions and Loading*

The inferior border of the mandible was completely constrained to simulate physiological support during mastication.

Dynamic cyclic loading conditions were applied to simulate functional occlusal forces. A total of 125,000 loading cycles were simulated using:

- Vertical load: 150 N
- Oblique load: 100 N

The loads were applied simultaneously on the occlusal surfaces of the posterior artificial teeth to reproduce functional masticatory loading.

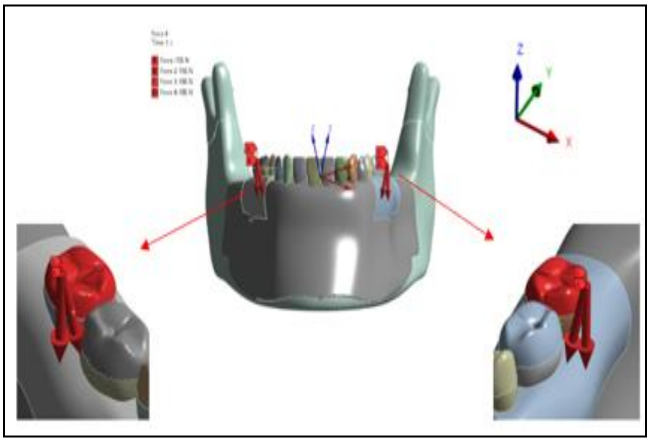


Fig 5 Loading Conditions Applied to the Finite Element Model Showing Vertical and Oblique Occlusal Forces

➢ *Outcome Measures*

The primary outcome variables analysed were:

- Maximum prosthesis displacement (mm)
- Overall von Mises stress (MPa)
- Stress distribution in peri-implant bone
- Stress distribution in prosthetic components
- Stress distribution in implant and locator attachment

Stress distribution was evaluated using colour-coded von Mises stress maps generated by ANSYS Workbench 2019. The maximum stress values for each component were recorded and compared between the two implant models. Descriptive analysis was performed to compare the biomechanical behaviour of the two models. As finite element analysis is a computational method with no biological variability, inferential statistical analysis was not performed.

III. RESULTS

The biomechanical performance of narrow diameter and wide diameter implants supporting mandibular implant-assisted distal extension cast partial dentures was evaluated using three-dimensional finite element analysis under dynamic loading conditions. The stress distribution and displacement patterns were analysed using von Mises stress criteria following 125,000 cycles of simulated functional loading.

➢ *Overall Prosthesis Displacement*

Maximum prosthesis displacement was observed at the distal extension denture base in both finite element models. The narrow diameter implant model demonstrated lower maximum displacement (0.16279 mm) than the wide diameter implant model (0.25882 mm), indicating improved resistance to prosthesis movement during functional loading.

Table 2 Maximum Prosthesis Displacement

Model	Maximum Displacement (mm)
Narrow Diameter Implant	0.16279
Wide Diameter Implant	0.25882

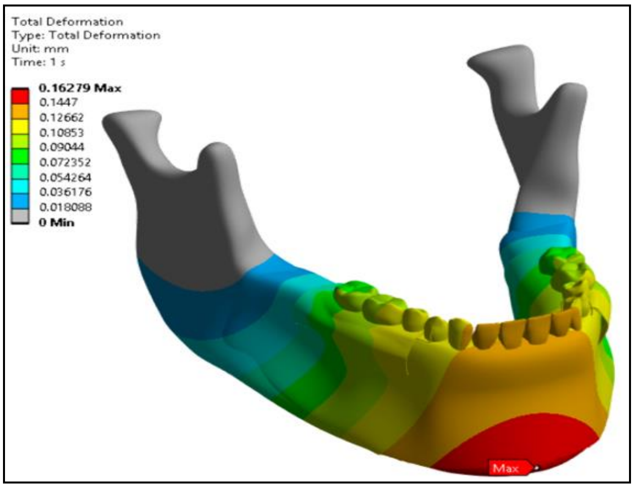


Fig 6 Overall Prosthesis Displacement in Model 1

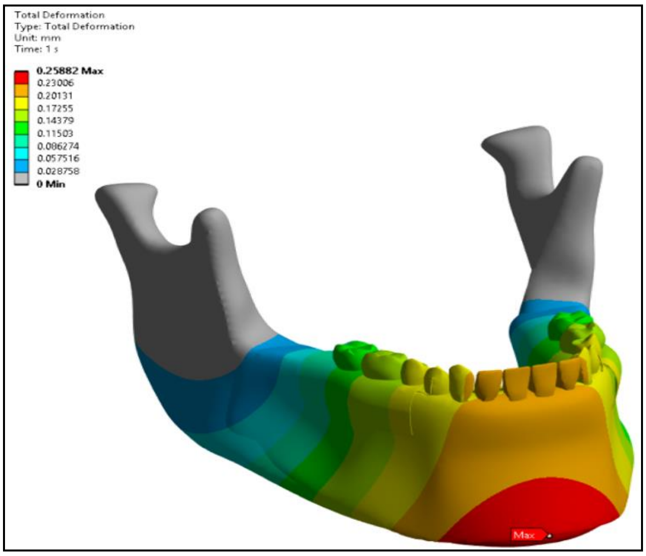


Fig 7 Overall Prosthesis Displacement in Model 2

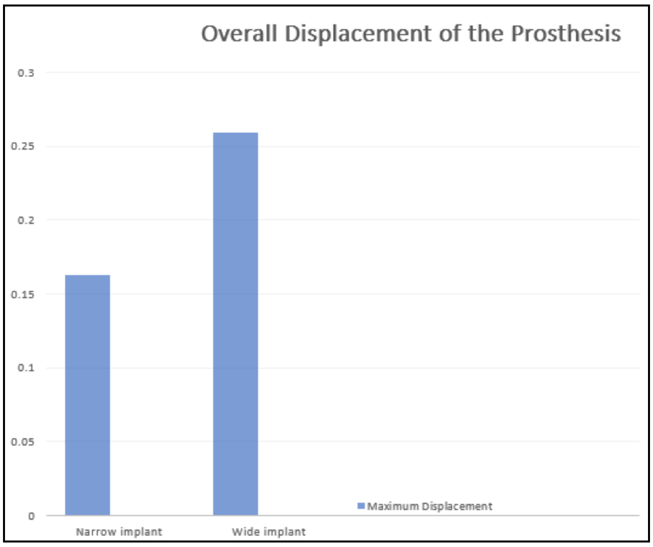


Fig 8 Graphical Comparison of Prosthesis Displacement between the Two Implant Models.

➢ *Overall von Mises Stress Distribution*

The maximum von Mises stress generated within the implant-assisted removable partial denture complex was lower in the narrow diameter implant model (290.49 MPa) than in the wide diameter implant model (310.19 MPa).

Table 3 Overall von Mises Stress Distribution

Model	Maximum Stress (MPa)
Narrow Diameter Implant	290.49
Wide Diameter Implant	310.19

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

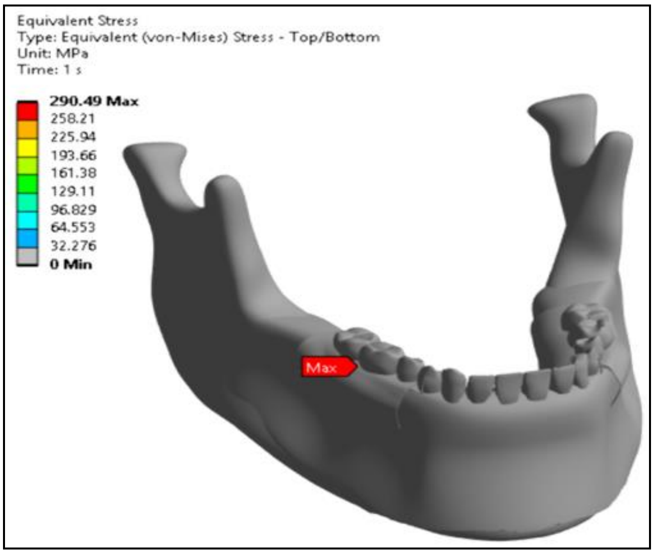


Fig 9 Overall Von Mises Stress Distribution in Model 1

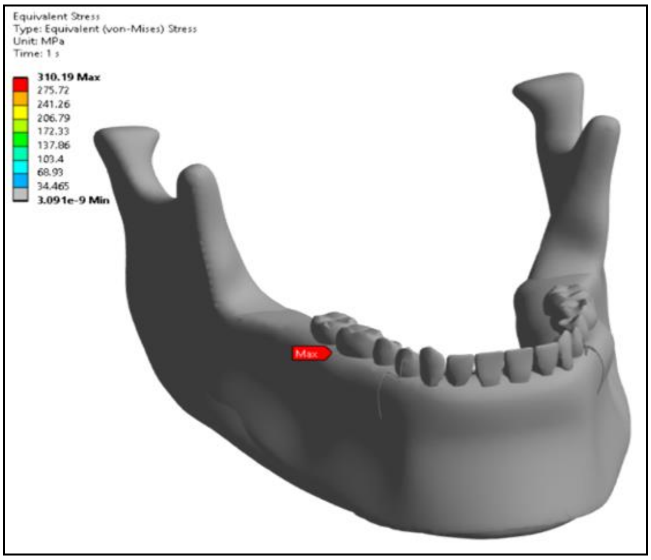


Fig 10 Overall Von Mises Stress Distribution in Model 2

➢ *Stress Distribution in Peri-Implant Bone*

Stress concentrations in the supporting bone were evaluated separately for cortical and cancellous bone.

The narrow diameter implant demonstrated lower stress concentration in both cortical and cancellous bone compared with the wide diameter implant.

Table 4 Stress Distribution in Supporting Bone

Structure	Narrow Implant (MPa)	Wide Implant (MPa)
Cortical Bone	51.713	56.776
Cancellous Bone	37.656	43.233

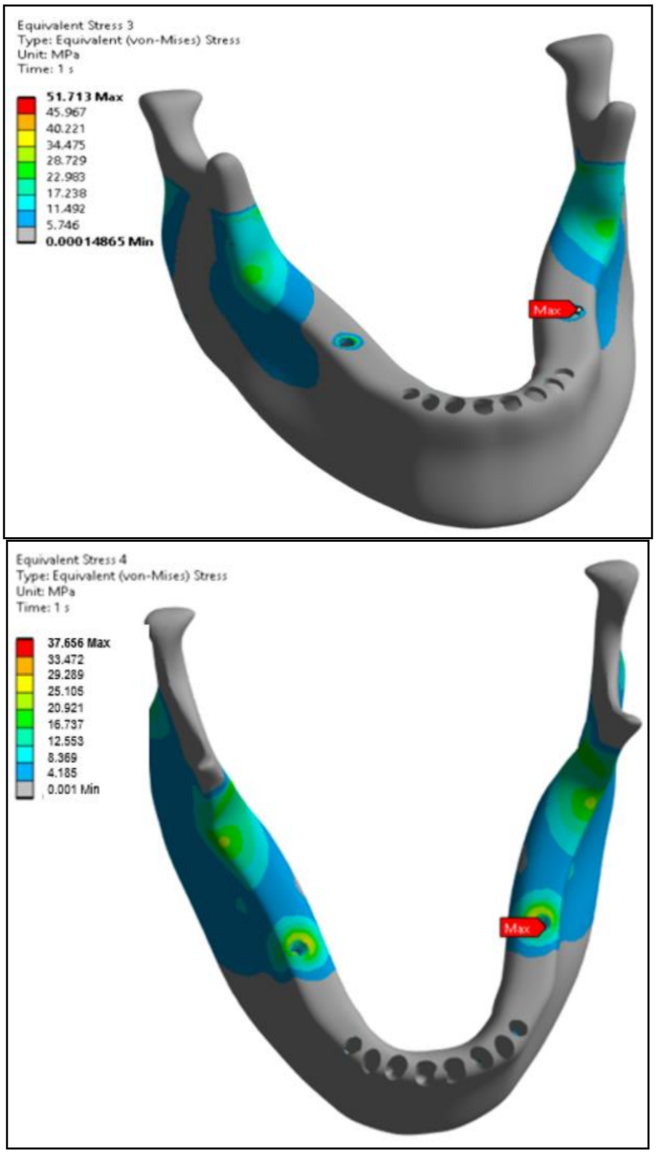
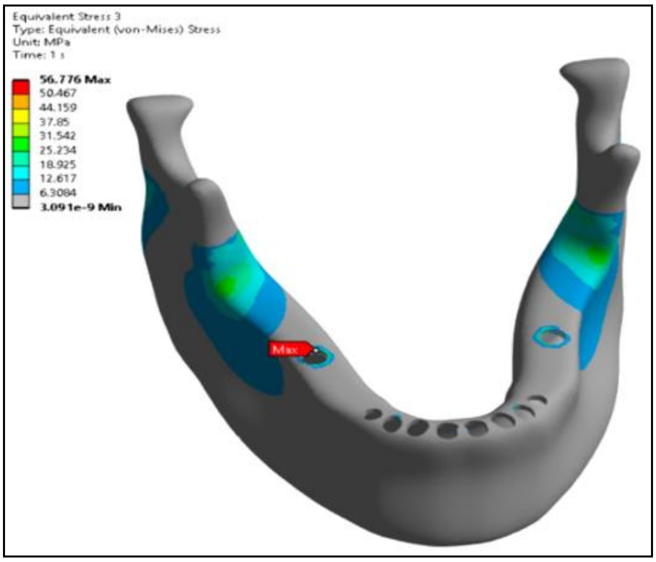


Fig 11 Stress Distribution in Cortical and Cancellous Bone in Model 1



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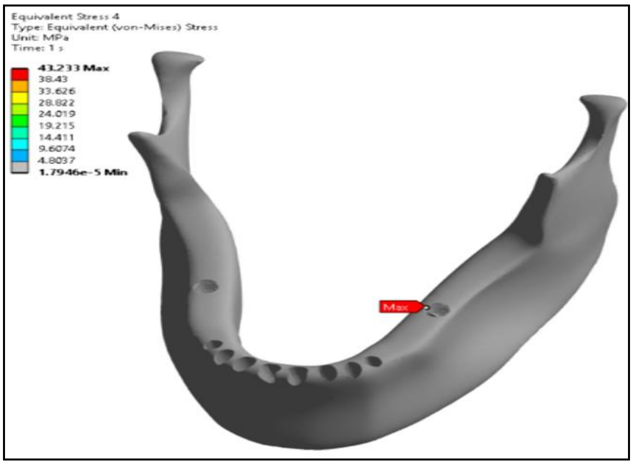

Fig 12 Stress Distribution in Cortical and Cancellous Bone in Model 2

➢ *Stress Distribution in Prosthetic Components*

The stress distribution in the abutment teeth, acrylic artificial teeth, acrylic denture base, and cobalt–chromium framework was evaluated under identical loading conditions.

The narrow implant model demonstrated slightly greater stress within the abutment teeth and acrylic denture base, whereas higher stress concentrations in the acrylic artificial teeth were observed in the wide implant model. The stress values recorded in the cobalt–chromium framework were comparable in both models.

Table 5 Stress Distribution in Prosthetic Components

Component	**Narrow Implant (MPa)**	**Wide Implant (MPa)**
Abutment Tooth	27.426	25.139
Acrylic Artificial Teeth	20.411	31.387
Acrylic Denture Base	25.917	17.506
Co–Cr Framework	158.57	159.10

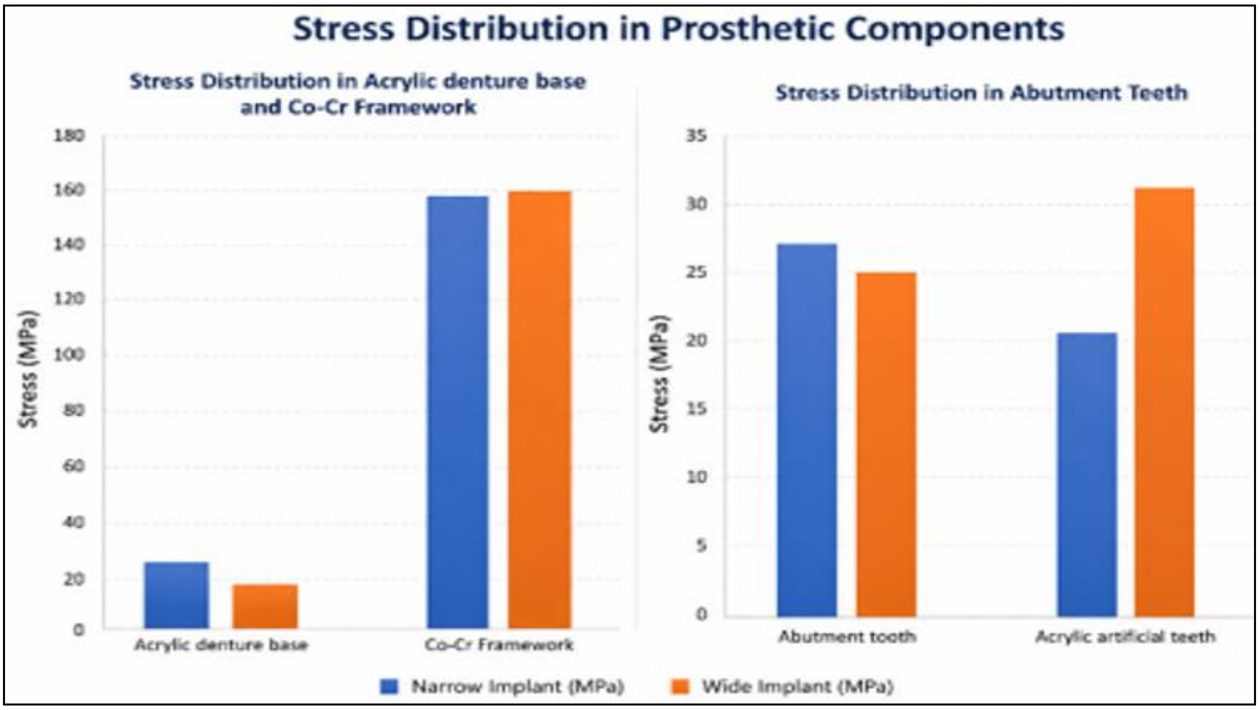

Fig 13 Graphical Comparison of Prosthetic Components between the Two Implant Models.

➢ *Stress Distribution in Implant and Locator Attachment*

The implant body and locator attachment assembly demonstrated favorable stress distribution in both models. The wide diameter implant exhibited marginally greater stress concentration within the implant–attachment complex than the narrow diameter implant.

IV. DISCUSSIONS

Implant-assisted removable partial dentures (IARPDs) have gained increasing acceptance as a conservative and predictable treatment option for the rehabilitation of Kennedy Class I distal extension cases. By providing posterior support through strategically placed implants, IARPDs reduce the rotational movement of the distal extension denture base, improve prosthesis stability, and distribute functional loads more favourably between the implants, abutment teeth, and supporting bone (9–12). The present finite element analysis compared the biomechanical behaviour of narrow and wide diameter implants under dynamic loading conditions to determine the influence of

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

implant diameter on stress distribution within the implant-assisted prosthetic system.

The results demonstrated that the narrow diameter implant model exhibited lower prosthesis displacement than the wide diameter implant model. Reduced denture displacement indicates greater resistance to rotational movement and improved biomechanical stability during functional loading. Posterior implant support transforms the distal extension removable partial denture from a predominantly tooth–tissue supported prosthesis into a tooth–implant supported prosthesis, thereby reducing vertical displacement of the denture base. These findings are consistent with previous finite element and clinical investigations, which reported improved support and decreased prosthesis movement following the incorporation of posterior implants in Kennedy Class I removable partial dentures (9–13).

The overall von Mises stress observed in the present study was also lower in the narrow diameter implant model. Although wider implants are generally considered advantageous because of their increased bone–implant contact area, the present findings suggest that implant diameter alone does not determine the biomechanical behaviour of the prosthetic system. Instead, stress distribution appears to be influenced by the combined effects of implant geometry, attachment design, prosthesis configuration, and the direction of functional loading. Similar observations have been reported by Naguib et al. (14), who demonstrated that implant dimensions influence stress transmission differently depending on the prosthetic design and loading conditions. Likewise, Bhattacharya et al. (15) reported that implant position and prosthesis configuration may have a greater influence on stress distribution than implant diameter alone.

Stress analysis of the supporting bone demonstrated lower stress concentrations in both cortical and cancellous bone surrounding the narrow diameter implants. Cortical bone is recognised as the primary load-bearing structure around dental implants because of its higher elastic modulus and greater resistance to deformation. Excessive stress concentration within cortical bone has been associated with marginal bone loss and long-term biomechanical complications. Therefore, the reduced cortical bone stress observed in the present study may represent a favorable biomechanical response that could contribute to improved preservation of peri-implant bone. Comparable findings have been reported in previous finite element investigations evaluating implant-assisted removable partial dentures under functional loading (13–16).

The wide diameter implant model demonstrated comparatively greater stress concentration within the implant–attachment complex and prosthetic components. This finding may be attributed to the increased rigidity of wider implants, which can transmit functional loads more directly to the surrounding prosthetic structures. In contrast, the narrow diameter implant appeared to permit a more gradual transfer of occlusal forces throughout the prosthesis, thereby reducing peak stress concentrations. Similar biomechanical behaviour has been described in finite element studies evaluating overdenture attachment systems, where the resilience of the attachment assembly significantly influenced stress transmission to both the implants and supporting bone (16–18).

The present study also demonstrated variations in stress distribution among individual prosthetic components. Slightly higher stresses were observed within the acrylic denture base and abutment teeth in the narrow implant model, whereas greater stresses were recorded within the acrylic artificial teeth in the wide implant model. However, these differences remained within physiologically acceptable limits and suggest redistribution rather than concentration of functional loads. The stress values recorded within the cobalt–chromium framework were comparable in both models, indicating that implant diameter had minimal influence on the structural integrity of the metal framework. These observations agree with previous biomechanical analyses reporting that framework design and connector rigidity contribute more substantially to stress distribution than isolated changes in implant diameter (15,16).

One of the distinguishing features of the present investigation is the use of dynamic cyclic loading rather than static loading. Most previously published finite element analyses have evaluated implant-assisted removable partial dentures using static vertical loads, which do not accurately reproduce the complex nature of masticatory function. Dynamic loading better simulates clinical conditions by incorporating repetitive functional forces that more closely resemble occlusal loading during mastication. Consequently, the present findings may provide a more clinically relevant representation of the biomechanical performance of implant-assisted removable partial dentures.

Despite the advantages of finite element analysis, several limitations should be considered when interpreting the results. The materials were assumed to be isotropic, homogeneous, and linearly elastic, whereas biological tissues exhibit anisotropic and viscoelastic properties. Complete osseointegration between the implant and surrounding bone was also assumed, which may not accurately represent clinical conditions. Furthermore, variations in bone quality, occlusal patterns, parafunctional habits, saliva, and long-term biological remodelling were not incorporated into the computational model. Therefore, the findings should be interpreted as biomechanical predictions rather than direct clinical outcomes.

V. CONCLUSION

Within the limitations of this three-dimensional finite element analysis, narrow diameter implants demonstrated more favorable biomechanical performance than wide diameter implants when used to support mandibular implant-assisted distal extension cast partial dentures under dynamic loading conditions. The narrow implant model exhibited lower prosthesis displacement, reduced overall von Mises stress, and more favorable stress distribution

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug701

within the supporting bone, while maintaining acceptable stress levels in the prosthetic components. These findings suggest that narrow diameter implants can be considered a viable treatment option for Kennedy Class I implant-assisted removable partial dentures, particularly in situations with limited bone width. However, further long-term clinical studies are necessary to validate these computational findings and establish their clinical relevance.

ACKNOWLEDGEMENT

We appreciate the technical assistance for finite element analysis from Anamac Design private limited, Haryana, India.

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