

"Comparative analysis of stress and strain in Co-Cr and PEEK frameworks for full-mouth rehabilitation using all-on-6 fixed dental prostheses"

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Abstract— Prosthetic rehabilitation of the atrophic maxilla is complex due to bone resorption and sinus pneumatization. This study evaluated stress distribution in All-on-6 implant-supported prostheses using Co-Cr and PEEK frameworks. 3D-printed skull-based models received implants in incisor, premolar, and pterygoid regions. Strain gauges were attached to prostheses fabricated with Co-Cr and PEEK. Results showed lower stress in the pterygoid region. Co-Cr exhibited overall lower stress, while PEEK effectively reduced strain on tilted premolar implants by dissipating forces to the terminal pterygoid implant. (Abstract)

Index Terms—All-on-6, Co-Cr framework ISCFDP, PEEK framework ISCFDP, implant superstructure, fire and forget digital impression making, FEA for implant superstructure.

I. INTRODUCTION

Edentulism causes alveolar ridge resorption, compromising denture stability. Implant rehabilitation in atrophic maxilla faces challenges due to poor bone quality [1] Maxillary bone (types III and IV) affects osseointegration, with cortical bone providing better stability [1] All-on-6 tilted implants improve stability, while pterygoid implants enable immediate loading [2] Long-span prostheses require strong materials. Co-Cr alloys offer biocompatibility and affordability, while PEEK provides durability, low solubility and corrosion resistance [9-10] The 3D finite element method evaluates stress distribution in All-on-6 with pterygoid support using PEEK and Co-Cr superstructures. The null hypothesis states difference in their stress distribution patterns.

II. MATERIAL AND METHODOLOGY

Model Preparation

A human skull was subjected to cone beam computed tomography (CBCT), and the resulting DICOM file was converted to STL format for 3D printing. The model was produced using fused deposition modeling with acrylonitrile butadiene styrene (AAROPRENE® from Aaron Industries Corporation, Gujarat, India), chosen for its elastic modulus similar to that of bone. Two 3D printed models, M1 with PEEK as superstructure and M2 with Co-Cr as superstructure were created to compare stress distribution in All-on-6 implant-supported complete fixed dental prostheses (ISCFDP). All models were coated with occlude spray (Diaswiss S.A., Switzerland) and scanned using a tabletop scanner (Shining 3D, India). The scans of M1-M2 were superimposed on their respective CT scans to standardize implant angulation. A surgical guide was printed (ANYCUBIC SLA UV Curing 3D Printer Resin B07G35CC1V, China) with sleeves for implant drills.

Virtual Planning of Implant Position

Virtual planning determined the size of the implants based on CBCT data, focusing on diameter and length.

Implant Placement

In both models two straight implants (3.3 mm diameter, 11 mm length) were placed in the incisor region, along with two tilted implants (3.75 mm diameter, 13 mm length) in the premolar area and two additional tilted implants (3.75 mm diameter, 16 mm length) in the pterygoid region.

Fabrication of Implant-Supported Complete Fixed Dental Prosthesis)

Multi-unit abutments (BioLine®) were installed on each implant to create a restorative platform. Multi-unit scan bodies (BioLine®) were placed on each implant, and both models were scanned (Shining 3D – Tabletop scanner, Hangzhou, China). The PEEK framework was designed using Exocad GmbH software (Darmstadt, Hessen, Germany) and printed (Shining 3D ACCUFAB D1S dental 3D printer, China) for M1. Co-Cr frameworks were designed for M2 followed by ceramic layering (Vintage Art, Shofu Inc.) following fire and forget philosophy of digital impression making by bioline implant at RR Dental lab, Vengal Rao Nagar, Hyderabad, Telangana, India.

Strain Gauge Analysis

Attaching strain gauge sensors

Ten strain gauges (TML JAPAN) were bonded to the buccal and lingual sides of each implant. Multi-stranded wires (TRI COM Cables, U.S.A) were attached to connect the sensors to an electrical signal conditioning unit (Data Acquisition System).

Loading conditions

A compression test was conducted to analyze the strain around each implant. A metal plate was placed on the ISCFDP for uniform contact across models, and each was subjected to a vertical load of 100 N, applied seven times using a universal testing machine (Model MCS 1000). The strain was recorded in microstrain units.

Finite Element Analysis

Meshing Procedures

The scanned model of the maxillary jaw with implants and each superstructure was used to create a finite element mesh, consisting of 689,283 elements and 932,842 nodes. The mesh was calibrated to reflect the elastic modulus of both cortical and cancellous bone and adjacent structures, subjected to appropriate masticatory loads to evaluate stress concentration in Co-Cr and PEEK framework in All-on-6 scenario.

Loading conditions

For finite element analysis (FEA), a vertical load of 100 N was applied bilaterally on each framework, equally distributed among the posterior teeth to account for variations in tooth count.

Stress analysis

FEA was conducted using Ansys 18.1 software (Ansys, Inc., Canonsburg, Pennsylvania), evaluating stresses in cortical and cancellous bone, implant stress, framework stress, and overall framework deformation under the 100 N load.

III. RESULTS

Table 1

IV. Comparison of mean values of different parameters at Stress distributed at 100N load between PEEK(M1) and Co-Cr(M2) groups using Mann Whitney test					
Parameter	Framework	Mean	SD	Mean Diff	p-value
Overall deformation	PEEK	0.00827	0.00130	0.00319	0.03*
	Co-Cr	0.00508	0.00127		
Overall stress (Mpa)	PEEK	19.2165	4.5364	-0.2073	0.96
	Co-Cr	19.4238	4.8579		
Cortical stress (Mpa)	PEEK	17.4645	4.2536	0.0536	0.98
	Co-Cr	17.4109	4.3545		
Cancellous stress (Mpa)	PEEK	1.5140	0.3837	0.14164	0.69
	Co-Cr	1.3724	0.3432		
Implant stress (Mpa)	PEEK	13.631	3.533	-0.061	0.98
	Co-Cr	13.692	3.424		
Frame stress	PEEK	9.4742	2.6894	-0.383	0.86
	Co-Cr	9.8572	2.4653		

* - Statistically Significant

The mean Overall deformation in PEEK framework was significantly higher [0.00827 ± 0.00130] as compared to Co-Cr framework [0.00508 ± 0.00127] and the mean difference between 2 groups was statistically significant at $p=0.03$. However, the mean Overall stress, cortical stress, Cancellous stress, Implant stress and Frame stress did not demonstrate significant differences between PEEK & Co-Cr Frameworks.

Table 2

Comparison of mean values of Micro Strain by strain sensors gauges positioned at Buccal & labial side between M1(PEEK) and M2(Co-Cr) groups using Mann Whitney test					
Side	Groups	Mean	SD	Mean Diff	p-value
Buccal Side	PEEK	177.00	78.47	47.37	0.34
	Co-Cr	129.63	45.70		
Labial Side	PEEK	66.50	10.61	46.25	0.03*
	Co-Cr	20.25	5.30		

* - Statistically Significant

The mean Micro Strain values for gauges positioned on Labial side in PEEK framework was significantly higher [66.50 ± 10.61] as compared to Co-Cr framework [20.25 ± 5.30] and the mean difference between 2 groups was statistically significant at $p=0.03$. However, the mean Micro Strain values for gauges positioned on Buccal side stress did not demonstrate significant differences between PEEK & Co-Cr Frameworks.

Table 3

Comparison of mean values of Strain by strain sensors gauges positioned at Buccal & labial side between M1(PEEK) and M2(Co-Cr) groups using Mann Whitney test					
Side	Groups	Mean	SD	Mean Diff	p-value
Buccal Side	PEEK	0.000177	0.000079	-0.000212	0.44
	Co-Cr	0.000389	0.000512		
Labial Side	PEEK	0.000067	0.000011	0.000047	0.04*
	Co-Cr	0.000020	0.000006		

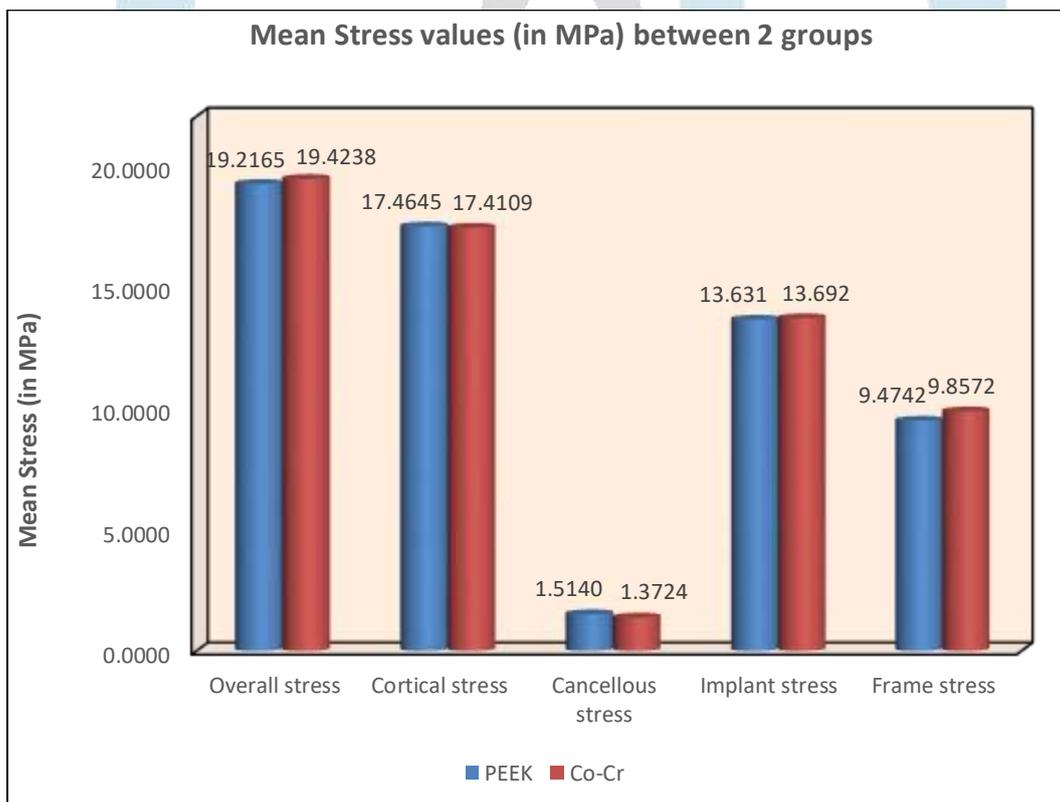
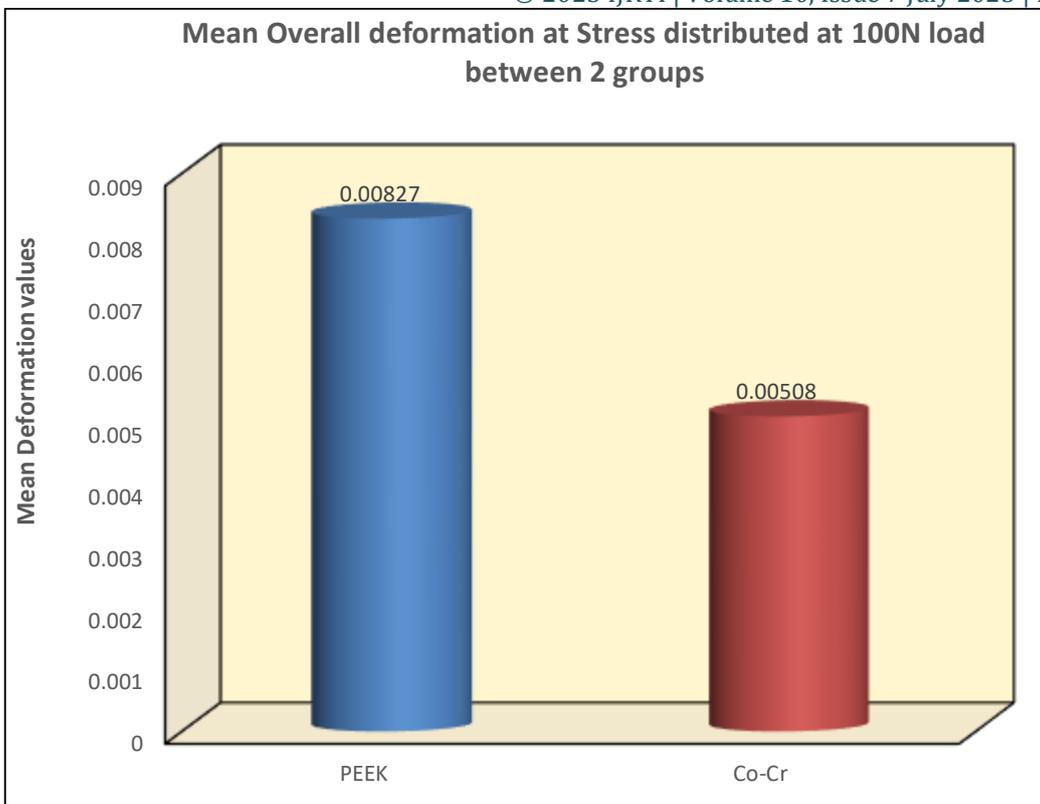
* - Statistically Significant

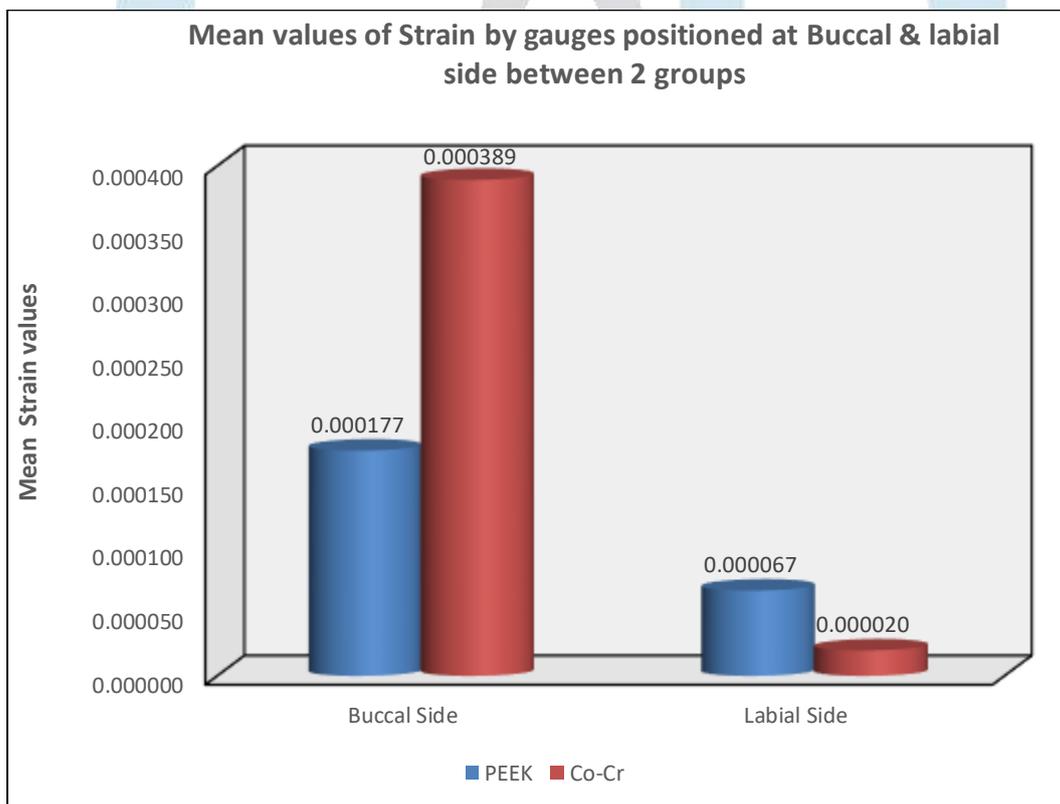
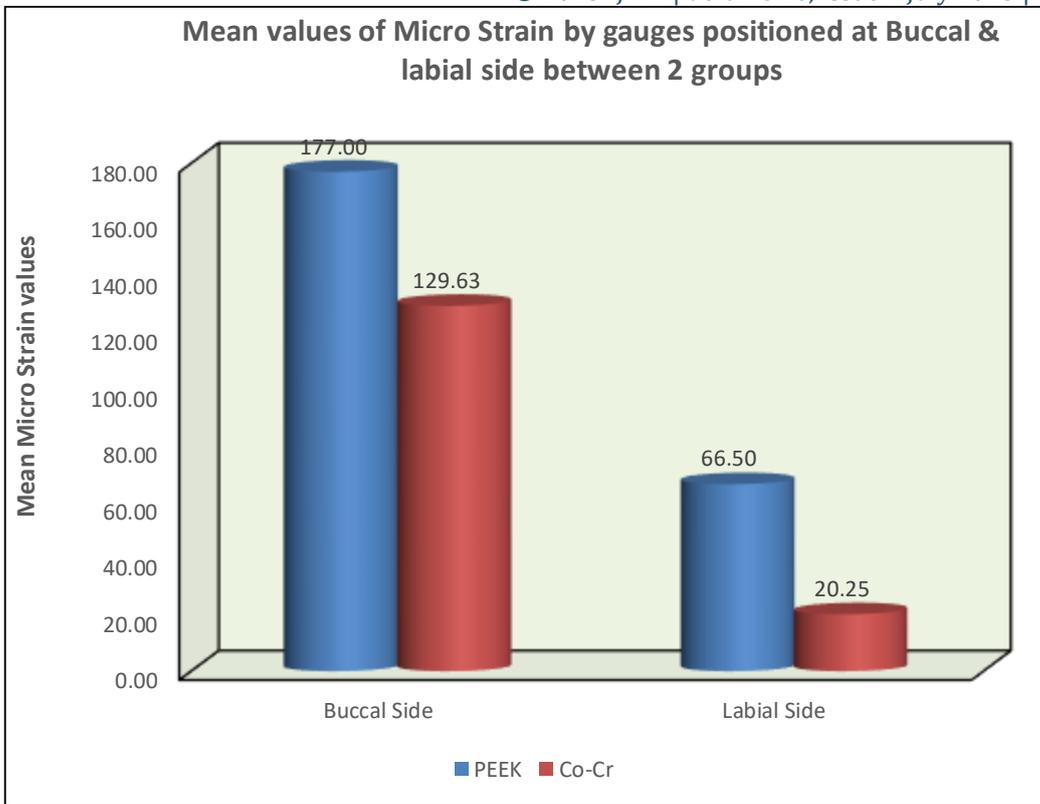
The mean Strain values for gauges positioned on Labial side in PEEK framework was significantly higher [0.000067 ± 0.000011] as compared to Co-Cr framework [0.000020 ± 0.000006] and the mean difference between 2 groups was statistically significant at $p=0.04$. However, the mean Strain values for gauges positioned on Buccal side stress did not demonstrate significant differences between PEEK & Co-Cr Frameworks.

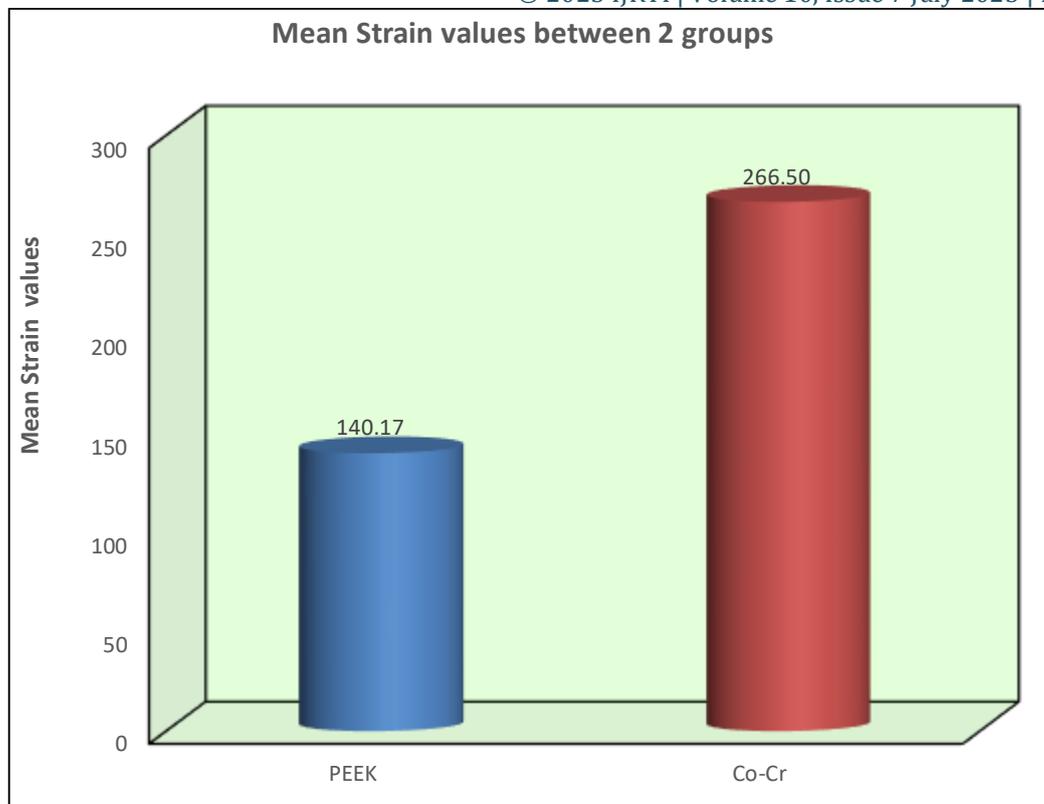
Table 4

Comparison of mean Strain values between M1(PEEK) and M2(Co-Cr) groups using Mann Whitney test					
Parameter	Groups	Mean	SD	Mean Diff	p-value
Strain	PEEK	140.17	83.51	-126.33	0.65
	Co-Cr	266.50	440.22		

The mean Strain values in Co-Cr framework was relatively higher [266.50 ± 440.22] as compared to PEEK framework [140.17 ± 83.51]. However, the mean difference between 2 groups was not statistically significant [$p=0.65$].







V. DISCUSSION

Prosthetic rehabilitation of the atrophic maxilla presents significant challenges.^[1] Paulo Malo's introduction of the All-on-4 technique in 1996 revolutionized implant dentistry by enhancing biomechanics through two straight anterior and two tilted premolar implants.^[7] However, its limitations, such as restricted A-P spread and short arch prostheses, led to the incorporation of additional implant sites to extend the arch.^[8-9]

The pterygoid region, known for its resistance to resorption due to multiple muscle attachments, offers strong anchorage for implants using multi-unit abutments. Pterygoid implants, supported by the maxillary tuberosity, palatine pyramidal process, and sphenoid pterygoid process, provide a reliable solution for the atrophic posterior maxilla. They demonstrate high success rates, minimal bone loss, few complications, and excellent patient acceptance. Given these advantages, this study utilizes the pterygoid region for implant placement to overcome the limitations of the All-on-4 technique.^[7-9]

The All-on-6 prosthesis gained popularity with the inclusion of pterygoid implants, enabling a more extensive framework across the arch. However, long-span prostheses present challenges such as bending and deformation under occlusal forces, leading to increased stress on the implant system. Excessive stress may result in mechanical complications, including screw loosening, framework fractures, and implant failure. Therefore, selecting an appropriate framework material is crucial for ensuring long-term stability and prosthesis longevity.^[9-10]

Selecting an appropriate framework material is crucial for the long-term success of implant-supported prostheses. Traditionally, Cobalt-Chromium (Co-Cr) and Nickel-Chromium (Ni-Cr) alloys have been widely used due to their mechanical strength and durability. However, with advancements in material science, Polyetheretherketone (PEEK) has emerged as a promising alternative due to its favourable biomechanical properties.^[10]

For patients with nickel allergies, Co-Cr alloys are preferred over Ni-Cr due to their superior biocompatibility, strength, lighter weight, and cost-effectiveness. Co-Cr also exhibits excellent mechanical properties, including high wear and corrosion resistance, making it a reliable choice for implant frameworks.

PEEK, a high-performance polymer, has gained attention for its unique advantages. Unlike metal frameworks, PEEK is lightweight, has shock-absorbing properties, and features an elastic modulus similar to bone. This similarity reduces stress on implants, potentially improving long-term outcomes. Additionally, PEEK offers durability, low solubility, and resistance to corrosion, making it particularly beneficial for cases where metal-free restorations are preferred.^[10]

Ultimately, the choice between Co-Cr alloys and PEEK depends on clinical needs, patient-specific factors, and biomechanical considerations. A well-chosen framework material minimizes mechanical complications, enhances prosthesis longevity, and optimizes patient comfort and satisfaction. As research continues, the search for even better materials remains an ongoing pursuit in the field of prosthetic rehabilitation.

This study compares and evaluates stress distribution and strain development beneath implant supported complete fixed dental prosthesis (ISCFDP) using Co-Cr and PEEK frameworks in an All-on-6 configuration through strain gauge analysis and finite element analysis (FEA).

To determine the stress distribution under the neck of ISCFDP was done by 2 different types of tests- strain gauge analysis and finite element analysis.

In this study strain gauge was attached to the labial surface of incisors, buccal surface of premolar and molar in all models. one strain gauge was bonded to the occlusal surface of ISCFDP.

A strain gauge was placed at the neck of the implant on the residual ridge, where stress is most concentrated. A vertical 100N load was applied seven times to simulate masticatory forces, and the mean values were analysed statistically.

When compressive force was applied by a universal testing machine the load was applied to the occlusal surface and the amount of displacement was measured. The compressive force reproduced the masticatory muscles with the measured strain value indicating the occlusal force.

Bahig et al conducted a clinical evaluation comparing PEKK and CoCr frameworks in mandibular fixed hybrid prostheses.

They reported a statistically significant increase in colonization (CFU) of Streptococcus and Neisseria at 2 and 4 weeks, and Candida at week 4 on PEKK frameworks compared to CoCr frameworks. Additionally, patient satisfaction was similar across both groups, except for taste alteration and bad smell, which were more prevalent with PEKK frameworks. These findings suggest that while PEKK frameworks may offer certain advantages, they may also be associated with increased microbial colonization and specific patient-reported issues.

Hazir et al—conducted a dynamic finite element analysis to evaluate the biomechanical behavior of various framework materials under masticatory loading conditions. They reported that the PEEK framework exhibited the highest maximum von Mises stress values (372.55 MPa) on the abutment and the highest maximum principal stress values (59.27 MPa) in the cortical bone. Additionally, the displacement of the PEEK framework was notably higher (0.35 mm) compared to Co-Cr (0.15 mm), indicating greater susceptibility to deformation. These findings suggest that while PEEK frameworks may offer certain advantages, their lower stiffness compared to materials like Co-Cr could lead to increased stress and displacement under dynamic loading, potentially impacting the long-term success of implant-supported prostheses.

This study suggests that while PEEK frameworks show greater deformation and strain, their overall stress distribution is comparable to Co-Cr. PEEK effectively dissipates stress toward the terminal pterygoid implant, reducing strain on tilted implants. Additionally, PEEK frameworks exhibit lower internal stress and better fit accuracy, whereas Co-Cr provides superior retention force. Although statistically significant differences exist between the two materials, the choice should be based on individual clinical and biomechanical needs for optimal prosthesis performance. Therefore, statistically the null hypothesis is accepted.

Abbreviations and Acronyms

- **ISCFDP** – Implant-Supported Complete Fixed Dental Prosthesis
- **PEEK** – Polyetheretherketone
- **Co-Cr** – Cobalt-Chromium
- **Ni-Cr** – Nickel-Chromium
- **FEA** – Finite Element Analysis
- **A-P** – Anteroposterior
- **CBCT** – Cone Beam Computed Tomography
- **STL** – Standard Tessellation Language (or stereolithography)
- **CAD/CAM** – Computer-Aided Design / Computer-Aided Manufacturing
- **N** – Newton (unit of force)

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