Sapporo Medical Journal
Volume 58, Issue 07, July 2024

Effect of PEKK and Bio-HPP CAD-CAM Materials on Stress Distribution around Implants in Bar-Retained Implant-Supported Prostheses

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Abstract— Introduction: Occlusal overloading compromises dental implant durability but using thermoplastic materials for bars in implant-supported overdentures is an effective solution to this problem. **Aim:** Evaluate the impact of using Polyetherketoneketone (PEKK) and Bio High-Performance Polymer (BioHPP) CAD/CAM materials on stress distribution around implants in bar-retained implant-supported prostheses. **Materials and methods:** A mandibular 3D-printed cast model from epoxy resin was used for this study, with selected implant sites surrounded by channels to allow a 2mm resin thickness between strain gauge rosettes and the implant. Two implants were inserted parallel to their sites in the model, and Ti-base abutments were screwed in. The impression was digitally scanned, and dental bars were designed. Eight identical bars (**n=4)**(four BioHPP and four PEKK) were milled using CAD/CAM. Strain gauges measured micro-strain around the implants, and stress analysis was conducted using a universal testing machine. Results were collected, tabulated, and analyzed with statistical software. **Results:** BioHPP milled bars have shown less force-transmitted and less traumatic effectson the implant and supporting structures**. Conclusion** BioHPP CAD-CAM Materials can be used as Bar-Retained Implant-Supported Prostheses.

Keywords: Bio-HPP, PEKK, CAD/CAM, Dental Implant, 3D printed.

Introduction

The treatment of complete edentulism has progressed from traditional complete dentures (CCDs) to more advanced options like implant-supported overdentures (IODs) and implant-supported fixed complete dentures. A significant innovation in this field is the use of bar attachments, which provide benefits such as improved load distribution, better retention, reduced post-insertion maintenance, and enhanced force transfer between implants, resulting in increased effectiveness and patient comfort.(Graziani and Tsakos, 2020; Elhelbawy et al., 2022)

Choosing an implant-retained overdenture attachment system involves various considerations: cost-effectiveness, retention strength, oral hygiene potential, anatomical accessibility for implants, the patient's social and functional needs, their expectations, the maxillomandibular relationship, inter-implant distance, and the condition of the opposing jaw. These factors help ensure the selected system is tailored to the patient's specific clinical and personal needs.(Karam eldain et al., 2023)

The Dolder bar joint, a wrought wire with a pear-shaped cross-section, is commonly used in implant-retained overdentures. It provides significant movement and lateral force resistance, connecting to the denture via an open-sided sleeve protected by acrylic resin or a lingual metal plate. BioHPP, a variant of PEEK, is being explored as an alternative bar material due to its low plaque affinity, bone-like elasticity, aesthetics, low density, and strong mechanical properties. Although promising, long-term clinical studies are needed to confirm its efficacy and safety. (Abdelrehim et al., 2022)

High-performance polymers like PEEK and PEKK from the Polyaryletherketones family are increasingly used in dentistry for their biocompatibility, lightweight nature, and superior thermal and mechanical properties. PEEK, with its bone-like elasticity and chemical stability, is preferred for implant-supported dentures and prosthetics, offering both aesthetic and functional benefits. BioHPP, a subtype of PEEK enhanced with ceramic fillers, is gaining traction in prosthetic dentistry due to its high mechanical properties, biocompatibility, shock absorption, abrasion resistance, low density, and color stability. These properties make it suitable for various dental applications, including removable partial denture frameworks, crowns, and implant abutments.(Jovanović et al., 2021)

PEKK is an emerging biomaterial for dental prostheses and implants, offering enhanced properties over PEEK, such as higher compressive strength and superior long-term fatigue resistance, making it a promising material in dental materials technology.(Vitalariu et al., 2021)

Strain gauges, essential in experimental stress analysis, measure mechanical stress by detecting changes in electrical resistance due to material strain. The bonded resistance strain gauge, the most common type, features a fine wire or metallic foil grid on a carrier matrix. Strain gauges are valued for their cost-effectiveness, small size, minimal temperature impact, and high sensitivity to strain, with applications ranging from testing aircraft wings to monitoring bridges.(Kaya et al., 2021)

Materials and Methods

Materials:
A total of 8 dental bars (n = 4) were fabricated and used in this study. Group A Pekkton® ivory (Milling Disk of PEKK) from Cendres+Métaux (Switzerland). Group B breCAM (Milling Disk of BioHPP) from Bredent breCAM (Germany). Loaded with Frontier ® (Titanium Implant) ∅3.75*13mm, coated with Riva (light cured resin reinforced glass ionomer restorative material) SDI (AUSTRALIA), used to simulate the integrated bony zoon. Ti-Base Hex 2.45 (Titanium Base abutment), and Scanbody Frontier® RP (Scan body) From GMI (Spain). Surrounded with Kyowa strain gauges (KFGS-1-120-C1-11-L1M2R) from KYOWA (Japan). Placing Mollosil (Chairside soft relining -long term), from DETAX (Germany) used as a cushion.

Methodology

- **Cast Model:**

  Utilizing the ANYCUBIC-Photon 3D printer with HARZ Labs printing material, a mandibular 3D-printed cast model was constructed. This model simulated the human mandibular jaw and included two parallel implant holes in the lower cuspid regions, surrounded by channels with flat walls. These channels aimed to accommodate rectangular strain gauge rosettes, allowing for a 2mm thickness of epoxy resin between the rosettes and the implant. A 2mm cutback was made for the placement of silicon resilient material (mollosil) to simulate oral mucosa soft tissue (Saad NT., Osman E., Abdelhamid AM., Shokry M., 2020).

- **Implant placement:**

The Frontier® implant surgical kit was used for the activation of implant holes. The procedure involved a gradual drilling process for implant insertion paths. Subsequently, Frontier® Titanium Implants (Ø3.75*13mm) coated with Riva (light cured resin reinforced glass ionomer restorative material) were inserted into the 3D-printed cast model to mimic osseointegration.

Figure 1: view after implant insertion

- **Soft tissue construction:**

  The construction process utilized Cavex molding wax to create the spacer and Acrostone cold cure acrylic material for the special tray. After the spacer was removed and the surface was scratched, the implant sites were covered with wax. Mollosil Chairside soft relining (long-term) was then applied using a special tray to construct artificial soft tissue.

Figure 20: Chairside soft relining -long term for simulating the soft tissue of the oral mucosa.

- **Bar design:**

  The process involved inserting Ti-Base Hex 2.45 into the implant sites and applying Scanbody Frontier® RP over the Ti-Base. Digital scanning of the cast was performed, and dental bar designs were created using EXOCAD 2018 software. Eight identical bars, divided into two groups, were milled from BioHPP and PEKK discs using a 5-axis CAD/CAM milling machine (DWX-52D®, DGShape, a Roland Company).

Figure 2: Eight identical bars divided into two groups (BioHPP & PEKK)

- **Sample size:**

According to(Charan and Biswas, 2013), the sample size was determined using the formula $N =((Z_\alpha)^2 * (SD)^2)/(d)^2$. The total sample size calculated was approximately 8 samples, divided into two groups(n = 4).

- **Grouping and Denture Construction:**

The specimens were divided into two groups for BioHPP and PEKK bars. A complete mandibular overdenture was constructed based on the 3D-printed cast model. This involved installing the bar and duplicating the entire cast with dental stone. The final overdenture was constructed with a Rhein83 single sleeve inserted into the bar.

Figure 3: Steps of denture construction.

- **Installation of Strain Gauge Rosettes and Load Application:**

Strain gauges were cemented at their terminal ends and placed parallel to the implant's long axis. The micro-strain was measured around the implant area. A universal testing machine applied compressive static loads (vertical and oblique) on the denture.

Figure4: view after installations of strain gauge rosettes

- **Test (Load application and strain recording measurement):**

The denture was placed on the cast, and wires on both sides were connected to the KYOWA strain gauge mater Type PCD-300A. A universal testing machine (LLOYD LR 5K) applied a compressive static load through a rounded rod applicator. A 100N load at a 0.5mm/min rate was applied unilaterally to the central fossa of the right first molar, then to the occlusal surfaces of both the right and left first molars. The cast model was then tilted by 30^{o} using a dental surveyor, and a 65N load at a 0.5mm/min rate was applied similarly. For each bar tested, loads were applied, micro-strains recorded, and stress distribution around the implant was statistically evaluated.(Saad NT., Osman E., Abdelhamid AM., Shokry M., 2020; Hegazy et al., 2020; Hasanin et al., 2021).

Figure 5: The universal testing machine (LLOYD LR 5K)

Figure 6: View showing screen load of the universal testing machine during the test.

Figure 7: Horizontal, Oblique, unilateral and bilateral load

Results

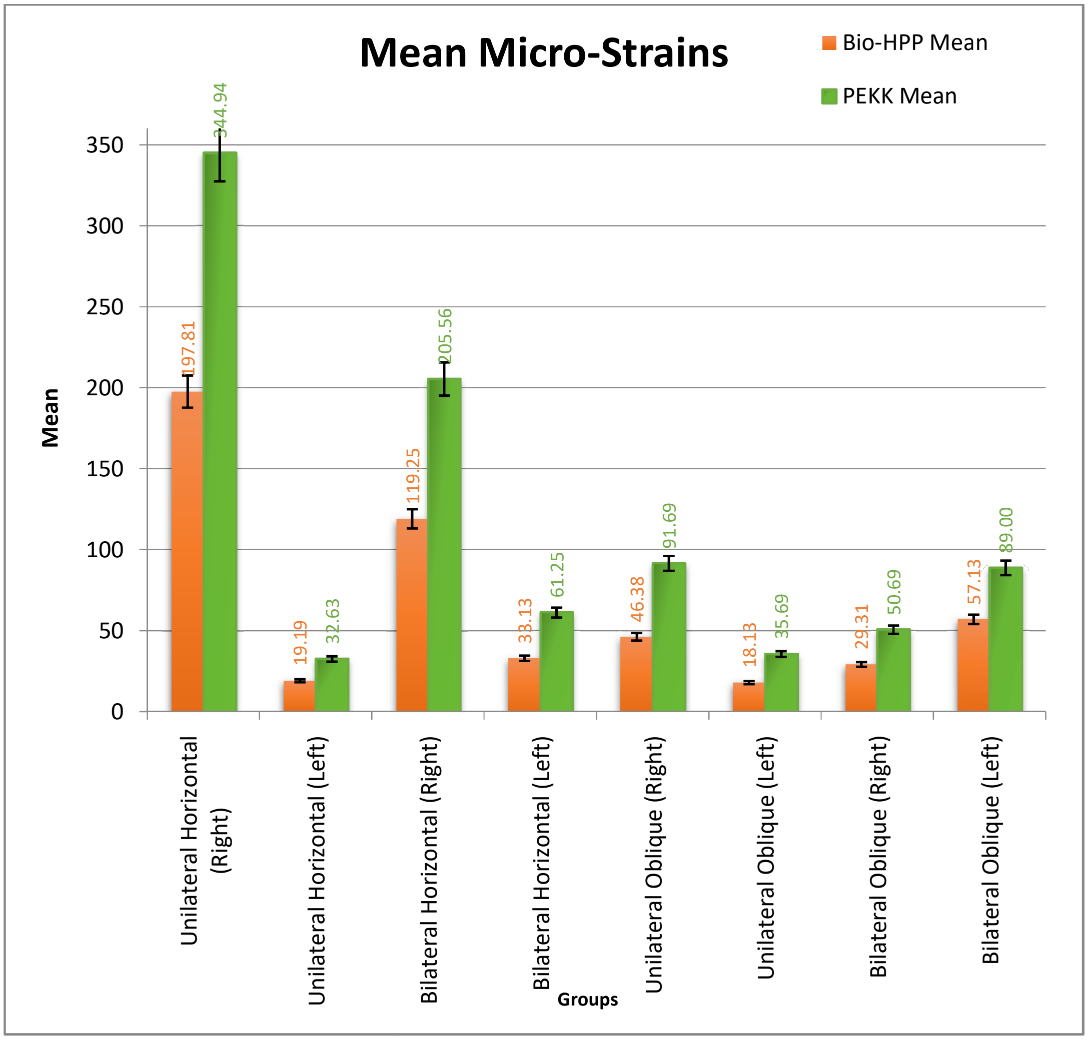
All specimens were divided into two groups (n=4/group).

Group A: Four BioHPP bars milled with CAD/CAM.

Group B: Four PEKK bars milled with CAD/CAM.

The loads were applied as the following: -

Condition	Bio-HPP Mean	Bio-HPP Std. Deviation	PEKK Mean	PEKK Std. Deviation	P-value
Unilateral Horizontal (Right)	197.81	2.91	344.94	1.3	<0.001
Unilateral Horizontal (Left)	19.19	1.26	32.63	1.11	<0.001
Bilateral Horizontal (Right)	119.25	1	205.56	1.73	<0.001
Bilateral Horizontal (Left)	33.13	1.23	61.25	0.78	<0.001
Unilateral Oblique (Right)	46.38	1.26	91.69	1.78	<0.001
Unilateral Oblique (Left)	18.13	1.13	35.69	0.83	0.012
Bilateral Oblique (Right)	29.31	1.41	50.69	1.92	<0.001
Bilateral Oblique (Left)	57.13	0.81	89	1.19	<0.001


Mean Micro-Strains
Bio-HPP Mean
PEKK Mean
Mean
350
300
250
200
150
100
50
0
197.81
344.94
19.19
32.63
119.25
205.56
33.13
61.25
46.38
91.69
18.13
35.69
29.31
50.69
57.13
89.00
Unilateral Horizontal (Right)
Unilateral Horizontal (Left)
Bilateral Horizontal (Right)
Bilateral Horizontal (Left)
Unilateral Oblique (Right)
Unilateral Oblique (Left)
Bilateral Oblique (Right)
Bilateral Oblique (Left)
Groups

Discussion

- **Discussion of materials and methods:**

This study evaluates the impact of PEKK and BioHPP CAD/CAM materials on stress distribution around implants in bar-retained prostheses using both in-vitro and in-vivo research techniques. An in-vitro study offers greater control over variables, excluding variations in tissues, ridge geometry, and human differences in tooth nature, periodontal support, and root shape and length. It also avoids issues related to oral hygiene practices and masticatory muscle strength, which are not controlled in clinical trials.(Deste and Durkan, 2020)

The main objectives of an implant overdenture are to distribute stress evenly and minimize forces applied to implants and peri-implant bone loss. Using 3D printing technology, the experimental model was constructed, and a 5-axis milling machine was employed to improve surface quality and accuracy in milling operations.(Lee et al., 2022).

Synthetic mucosa made of silicone (Gingival Mask) was used to model the mucosa beneath the denture-bearing area, chosen for its minimal permanent deformation, low dimensional changes, quick recovery time, and positive impact on prosthetic design.(Rostom and Ragheb, 2021)

Traditionally, cobalt chromium (Co-Cr) alloys have been used for attachment systems, but concerns over metallic taste and allergic reactions have led to the use of zirconia (ZrO2) and polyetheretherketone (PEEK). PEEK, enhanced with 20% ceramic fillers to create BioHPP, is biocompatible, has good mechanical properties, a low modulus of elasticity, and low surface hardness. BioHPP's properties make it a strong candidate for replacing conventional bar materials, reducing issues like gingival hyperplasia, maintenance needs, peri-implant stress, and mucosal health problems. (Abdelrehim et al., 2022)

A hybrid PEEK-based, ceramic-reinforced high-performance polymer, BioHPP, is widely used in dentistry. PEKK shows an 80% higher compressive strength and better long-term fatigue properties than PEEK. Strain gauge technology was used to evaluate the stresses transferred to supporting structures with two standard implants sustaining an overdenture, offering sensitive, accurate, and reliable in-vitro stress analysis.(Vitalariu et al., 2021)(Jovanović et al., 2021)

In-vitro experiments used 100N loading magnitudes to replicate typical masticatory pressures, conducting unilateral and oblique loading to simulate chewing patterns. An oblique load was applied to simulate masticatory load and muscle force, targeting the area between the second premolar and first molar, where most patients chew.(Mendes Tribst et al., 2020)

- **Discussion of the result:**

In this study, bilateral loading was applied at the occlusal surfaces of the first molars, while unilateral force was applied to the central fossa of the first molar of a mandibular overdenture (Helaly, 2023). The first molar was chosen for loading due to the maximum occlusal forces exerted in this area where there is maximum contraction of all elevator muscles.

During occlusal loading, an implant overdenture experiences a range of forces in various directions. The bone-implant complex will experience tension and strain depending on the proximity of the load application site (Aboelnagga and El Sadat, 2022). When posterior loads are applied, the overdenture tends to rotate anteriorly around the fulcrum line, causing the denture to disengage from the unloaded side and reducing the micro-strain transmitted to that side. (Giudice et al., 2022)

The quadrilateral design distributes stresses evenly between the ridge and the implants through its splinting action, involving more planes and providing beneficial support under bilateral loads. However, under unilateral loads, the prosthesis rotates, concentrating strains at the loaded implants and ridge. (Tribst et al., 2020). The majority of the load is absorbed by implants closer to the load application, leading to statistically significantly larger mean micro-strains on the loaded side compared to the unloaded side during unilateral loading(Allam et al., 2022)

Summary and Conclusion

- **Summary:**
  This in-vitro comparative study evaluated the effect of PEKK and BioHPP CAD/CAM materials on stress distribution around implants in bar-retained implant-supported prostheses. Using a 3D-printed mandibular cast model made from epoxy resin, two implants were inserted parallel to their sites, and Ti-base abutments were screwed in. The impression was digitally scanned, and dental bars were designed using exocadsoftware. CAD/CAM technology was used to mill eight identical bars, divided into two groups: four bars from BioHPP material (Group A) and four bars from PEKK material (Group B). Strain gauges were cemented around the implants to measure micro-strain, and stress analysis was conducted using a universal testing machine. Results were collected and analyzed.
- **Conclusion:**
  Within the limitations of this in-vitro study, BioHPP material was found to be better than PEKK material for milling bars with CAD/CAM. BioHPP bars transmitted less force to the implant supporting structures, were less traumatic to the implants, and contributed to greater conservation and durability of the implants in bar-retained implant-supported prostheses.
- **Recommendation:**

  Further research and clinical trials are required to explore this material and possible modifications for further dental applications.

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