

UNIVERSITI TEKNOLOGI MARA

**THE EFFECT OF METAL- AND
POLYMER-BASED REMOVABLE
PARTIAL DENTURE FRAMEWORK
ON THE PROGNOSIS OF
TERMINAL ABUTMENT TOOTH**

**NOR FAHARINA BINTI ABDUL
HAMID**

PhD

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NOR FAHARINA BINTI ABDUL HAMID

Thesis submitted in fulfilment
of the requirements for the degree of
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ABSTRACT

Introduction: The biomechanical behaviour of removable partial denture (RPD) frameworks is important for the prognosis of terminal abutment teeth. With increasing use of polyetheretherketone (PEEK) as an alternative to cobalt chromium (CoCr), integration of finite element analysis (FEA) with clinical validation is required. **Objectives:** To evaluate the biomechanical behaviour of PEEK and CoCr RPD frameworks using FEA and to assess clinical and periodontal outcomes of terminal abutment teeth in Kennedy Class II patients over six months. **Methodology:** A combined FEA and clinical study were conducted. FEA models were developed from cone beam computed tomography data, comparing lingual bar and lingual plate designs under 120 N bilateral loading. Stress distribution and deformation in the framework, periodontal ligament (PDL), and mucosa were analysed. Clinically, terminal abutment teeth supporting PEEK (n = 16) and CoCr (n = 12) RPD were evaluated for periodontal parameters and patient reported oral health related quality of life was assessed using the Oral Health Impact Profile-14 questionnaire. **Results:** FEA demonstrated distinct biomechanical behaviours between materials, connector designs, and rest positions. PEEK bar designs showed gentler stress transmission to the PDL and mucosa, with 69–80% lower deformation than PEEK plates, but exhibited 24% higher internal framework stress. PEEK plate designs produced more even load sharing between the PDL and mucosa, supporting their use in patients with compromised periodontal support. CoCr bar designs demonstrated superior performance with 44–57% lower Von Mises Stress in framework, PDL, and mucosa compared with CoCr plates, while CoCr plates are more suitable for patients with strong abutments. Rest position effects were material dependent. In PEEK frameworks, mesial rests reduced internal framework stress by up to 43%, whereas distal rests lowered PDL stress by 49–89%. In CoCr designs, distal rests provided greater abutment protection, reducing PDL stress by 76% in plates and 46% in bars. Clinically, both groups showed comparable periodontal outcomes and significant improvement in quality of life, with no significant intergroup differences. **Conclusions:** Although FEA identified material and design dependent differences in stress distribution and deformation, these biomechanical variations did not translate into clinically detectable differences in periodontal stability or patient reported outcomes within the six-month observation period.

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LIST OF SYMBOLS

Symbols

E	Young modulus
ν	Poisson ratio
mm	Millimetre
MPa	Megapascal
N	Newton
σ	Stress
ε	Strain

LIST OF ABBREVIATIONS

Abbreviations

3D	Three Dimensional
AKP	Aryl Ketone Polymer
AM	Additive Manufacturing
CAD	Computer-aided Design
CAL	Clinical Attachment Loss
CAM	Computer-aided Manufacturing
CBCT	Cone Beam Computed Tomography
CNC	Computer Numerical Control
CoCr	Cobalt-chromium
CP Ti:	Commercially Pure Titanium
DRP	Direct Rapid Prototyping
DM	Direct Resin Milling
FEA	Finite Element Analysis
IM	Indirect Milling
IRP	Indirect Rapid Prototyping
PDL	Periodontal Ligament
PMMA	Polymethyl Methacrylate
POM	Polyoxymethylene
PPD	Periodontal Pocket Depth

PEAK	Poly-aryl-ether-ketone
PEEK	Poly- ether-ether-ketone
RPDs	Removable Partial Dentures
SLM	Selective Laser Melting
STL	Standard Tessellation Language
TM	Tooth Mobility
LWT	Lost-wax technique;
OHIP-14	Oral Health Impact Profile–14
OHRQoL	Oral Health Related Quality of Life
VMS	Von Mises Stress

CHAPTER 1

INTRODUCTION

1.1 Research Background

The rise in partially dentate individuals in Malaysia reflects the country's ageing population and improved tooth retention trends. According to the National Oral Health Survey of Adults (NOHSA) 2020, 34.3% of Malaysians aged 60 years and above retained at least 20 natural teeth, an improvement from 21.7% in 2010 and 21.5% in 2000 (Ministry of Health, 2013, 2025). However, the survey also revealed that partial edentulism remains highly prevalent among older adults, with many still requiring prosthodontic rehabilitation to restore function and aesthetics. The National Oral Health Strategic Plan (NOHSP) 2022–2030 emphasizes the increasing demand for removable prosthodontic services, particularly removable partial dentures (RPDs), as a cost-effective and accessible treatment option for partially edentulous patients in public healthcare settings (Ministry of Health, 2025). Despite advances in fixed and implant prosthodontics, RPDs continue to play a central role in Malaysia's oral rehabilitation strategies due to their affordability, reversibility, and ability to restore oral function in patients with multiple missing teeth or systemic limitations.

It has been demonstrated that RPDs influence the prognosis of the remaining teeth, particularly those that serve as terminal abutments, in two ways. First, they tend to promote plaque accumulation around the teeth, which can lead to dental caries, periodontal disease, and eventually tooth loss. Second, the RPD components may exert harmful lateral forces on the terminal abutment tooth during function, resulting in tooth mobility, tilting, and opening of proximal contacts, which can lead to food impaction and its sequelae, including caries, periodontal disease, and ultimately tooth loss. These biological and mechanical factors often act synergistically, accelerating abutment deterioration over time. Recognising this interrelationship, the present study employs a dual investigative approach, finite element analysis (FEA) to simulate and quantify stress distribution within the prosthetic–biological interface, and a clinical validation study to evaluate the corresponding biological and periodontal responses in patients rehabilitated with RPDs. This integrative strategy bridges computational modelling

with clinical observation, thereby enhancing the understanding of how framework material and design influence the prognosis of terminal abutment teeth.

RPDs are traditionally cast by manually waxing a framework on a refractory cast. However, computer-aided design and manufacturing (CAD/CAM) technology has recently been used in the processing of dental prostheses, including RPDs (Refai et al., 2022; Harb et al., 2019; Williams et al., 2006). The framework material, made using CAD/CAM technology, may include rigid materials such as chrome cobalt and less rigid materials such as polyetheretherketone (PEEK). Recent bibliometric analyses have highlighted PEEK as a high-impact keyword in RPD research, reflecting its growing significance in the field due to its unique material properties (Hamid et al., 2024).

Rigid metallic frameworks have traditionally been preferred because of their ability to distribute functional stresses across the arch, thereby minimising concentrated loads on abutment teeth and supporting tissues (Phoenix et al., 2003). However, the biomechanical behaviour of less rigid polymer-based frameworks, such as PEEK, remains less well understood. While their elasticity may enhance patient comfort and aesthetics, it could potentially lead to unfavourable stress transmission to the terminal abutments and residual ridge.

In response to this lack of integrated biomechanical and clinical evidence, the present study explores the biomechanical performance and biological response of rigid (CoCr) and non-rigid (PEEK) RPD frameworks. Through FEA modelling and clinical follow-up, this study aims to elucidate how framework material and design affect stress distribution, periodontal health, and the overall prognosis of terminal abutment teeth. The findings are expected to contribute toward evidence-based recommendations for the use of polymer-based frameworks in clinical practice.

1.2 Problem Statements

Removable partial dentures (RPDs) remain a widely used and cost-effective treatment for partially edentulous patients. Still, their use can negatively affect the prognosis of the remaining teeth, especially the terminal abutments. Biologically, RPD components may encourage plaque accumulation and increase the risk of caries and periodontal disease. Mechanically, improper framework design can transmit harmful lateral forces to the abutments, leading to tooth mobility, proximal contact opening, and eventual tooth loss.

Cobalt–chromium (CoCr) has long been the material of choice for RPD frameworks due to its rigidity and durability. However, the fabrication process is complex, and the metallic colour may be unsightly. Polyetheretherketone (PEEK), a tooth-coloured polymer processed via CAD/CAM, has emerged as an attractive alternative. Despite its aesthetic and processing advantages, its lower elastic modulus may cause uneven load distribution and concentrated stress on abutment teeth and residual ridges.

Additionally, currently no study has integrating finite element analysis (FEA) with clinical outcomes in the evaluation of RPD frameworks, particularly in correlating biomechanical behaviour with short term clinical performance. The biomechanical and clinical effects of this flexible material remain underexplored. Therefore, this study investigates the biomechanical behaviour and biological responses associated with rigid (CoCr) and non-rigid (PEEK) RPD frameworks using FEA and clinical validation, including assessment of patients' oral health–related quality of life (OHRQoL) using the Oral Health Impact Profile-14 (OHIP-14) instrument.

1.3 Scope of Study

This study evaluates the effects of framework material rigidity on the prognosis of terminal abutment teeth in removable partial dentures (RPDs). Two types of RPD frameworks were investigated: a rigid CoCr framework and a non-rigid PEEK framework. The study was conducted in two complementary phases.

In the finite element analysis (FEA) phase, three-dimensional models of mandibular Kennedy Class I RPDs were developed to simulate stress distribution within the abutment teeth, periodontal ligament, and supporting structures under masticatory loading. The FEA aimed to quantify differences in stress concentrations and deformation patterns across different framework designs for each material.

In the clinical phase, partially edentulous patients rehabilitated with CoCr and PEEK frameworks were evaluated over a six-month period as an early phase evaluation to capture initial biological response, periodontal changes, and patient adaptation to the prosthesis. The periodontal parameters of the terminal abutment teeth were assessed to determine biological responses, while patient-reported outcomes were measured using the OHIP-14 questionnaire to assess the impact on OHRQoL.

This study was limited to mandibular Kennedy Class I cases with healthy abutment teeth and controlled periodontal conditions. Maxillary cases, unilateral edentulism, and patients with systemic and periodontal diseases were excluded.

1.4 Research Questions

How does framework material rigidity (CoCr versus PEEK) influence stress distribution and deformation within terminal abutment teeth, periodontal ligament, and supporting structures under simulated masticatory loading?

- i. How does framework design interact with material rigidity to modify stress transmission patterns in mandibular Kennedy Class I RPDs?
- ii. What are the longitudinal effects of CoCr and PEEK RPD frameworks on the periodontal health of terminal abutment teeth over a six-month clinical period?
- iii. Are there differences in OHRQoL, as measured by the OHIP-14, between patients rehabilitated with CoCr and PEEK RPD frameworks?
- iv. To what extent do FEA predictions of stress and deformation correspond with observed clinical periodontal outcomes in patients wearing different RPD framework materials?

1.5 Research Objectives

1.5.1 General Objective

To evaluate the biomechanical behaviour, clinical periodontal response, and patient-reported outcomes associated with rigid (CoCr) and non-rigid (PEEK) RPD frameworks, with specific emphasis on the prognosis of terminal abutment teeth.

1.5.2 Specific Objective

To quantify and compare stress distribution and deformation patterns in terminal abutment teeth (periodontal ligament) and supporting structures of CoCr and PEEK RPD frameworks using FEA.

- i. To assess the influence of framework design, in conjunction with material rigidity, on stress transmission under simulated masticatory loading conditions.
- ii. To evaluate and compare changes in periodontal parameters of terminal abutment teeth in patients rehabilitated with CoCr and PEEK RPD frameworks over a six-month follow-up period.
- iii. To compare OHRQoL between patients wearing CoCr and PEEK RPD frameworks using the OHIP-14 questionnaire.
- iv. To correlate the FEA findings with clinical outcomes to validate the predictive value of biomechanical modelling in prosthodontic research.

1.6 Hypothesis

Null Hypothesis (H_0): There is no significant difference between cobalt–chromium (CoCr) and polyetheretherketone (PEEK) removable partial denture (RPD) frameworks in terms of stress distribution, periodontal response, and OHRQoL among patients rehabilitated with these frameworks.

1.7 Significance of Study

This study bridges the gap between biomechanical simulation and clinical validation in evaluating RPD frameworks. By integrating FEA with clinical outcomes, it provides a comprehensive understanding of how framework rigidity influences stress distribution and the biological response of terminal abutment teeth.

Scientifically, the study contributes to current knowledge of polymer-based materials, particularly PEEK, by comparing its stress transmission characteristics with those of conventional CoCr frameworks. The dual analytical and clinical approach enhances the evidence base for material selection and optimisation of RPD design.

Clinically, the findings provide insight into how framework material affects abutment prognosis and patient comfort. The inclusion of patient-reported outcomes, as measured by the OHIP-14, further supports a patient-centred evaluation of oral rehabilitation.

1.8 Thesis Outline

This thesis comprises six chapters: introduction, literature review, methodology, results, discussion, conclusion, and future recommendations. The following chapter (Chapter 2) starts with the biomechanics of RPDs in relation to abutment teeth. This chapter provides an overview of PEEK, highlighting its mechanical properties and summarizing previous studies on PEEK RPD frameworks, including both clinical findings and in vitro evaluations. The chapter concludes with a review of FEA in RPD research. Chapter 3 presents the methodology and process used in the design and fabrication of RPDs in FEA and clinical studies. Chapter 4 presents the results of the data analysis, along with the statistical analysis. Chapter 5 covers the discussion, followed by the conclusion of this research and recommendations for future research in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the theoretical and empirical foundations relevant to the evaluation of removable partial denture (RPD) frameworks. The review begins with a discussion of the biomechanical principles of removable partial dentures (RPDs), including their effects on abutment teeth and oral mucosa. This is followed by an overview of the materials and fabrication techniques used in constructing RPD frameworks, with particular emphasis on the emerging material polyetheretherketone (PEEK). The section on PEEK also addresses specific considerations in designing PEEK RPDs, incorporating evidence from previous case reports, clinical studies, and in vitro research. Finally, the chapter concludes with a review of the literature on finite element analysis (FEA) as it relates to RPDs.

2.2 The Biomechanics of Removable Partial Denture's Design

In Kennedy Class I situations, the lack of posterior abutments poses significant biomechanical challenges for RPD. Kennedy Class I defines a partially edentulous arch with bilateral, posterior, free-end saddle areas. It represents the loss of posterior teeth on both sides of the mouth, with no natural teeth remaining behind the edentulous spaces. The terminal abutment teeth are subjected to substantial mechanical stresses during mastication because the components of the RPD, such as rests and clasps, are typically placed on them. The periodontal ligament (PDL), which acts as a cushion between the tooth and the surrounding bone, plays a critical role in absorbing and distributing these mechanical stresses. Similarly, the mucosa underlying the denture base serves as a supportive and load-bearing structure, helping to distribute functional forces to the underlying bone and soft tissues. However, due to the differences in the displaceability of the PDL of the terminal abutment teeth and the soft tissue over the distal edentulous ridge, rotational movement of the RPD often occurs under functional loads.

The biomechanical interaction between the oral structures and the dental prostheses is a crucial factor that plays a role in the success of dental treatment over the long term (Phoenix et al., 2003; McGivney & McCracken, 1995). The biomechanical principles for the design of RPDs are centred on stress control, i.e., the distribution of forces to the supporting structures to ensure stability and retention of the RPDs and the preservation of the remaining teeth and residual ridges (McGivney & McCracken, 1995). In order to provide well-functioning RPDs, an attempt must be made to maintain a stable prosthesis. RPDs allows it to move in different planes and axes (fulcrums) that are perpendicular to the plane which can cause stresses to be applied to the teeth and underlying tissues that can be harmful if they exceed the tissue's physiological tolerance.

These can be made possible by incorporating a rigid framework in the denture that acts as a major connector that distributes forces to as much of the supporting structures as possible. The RPD is supported not only from the remaining teeth but also from the mucosa covering the residual ridge (denture-bearing area). Therefore, it is important to maximize the number of abutment teeth used for support while keeping the design as simple as possible. At the same time, the denture should extend over as much of the denture-bearing area as possible to optimize load distribution during mastication.

A terminal abutment is a natural tooth that provides primary support and retention, marking the boundary of the edentulous span. It plays a dual role; in addition to supporting the prosthesis, they also provide retention through engagement of their undercuts by the retentive elements of the framework (Phoenix et al., 2003; McGivney & McCracken, 1995). If an RPD cannot effectively distribute occlusal forces across the arch, concentrated stresses may develop on the abutment teeth and residual ridge. Excessive stress on abutment teeth can lead to mobility, tilting, migration, and mesial contact opening, while concentrated ridge stress accelerates residual ridge resorption and compromises denture stability. As a result, a correct framework design made of an appropriate material is critical in order to address not only the denture's retention and stability, but also how stress is distributed on the abutment teeth and surrounding tissues (Mousa et al., 2021).

2.3 Removable Partial Denture's Design Requirements

Designing a RPD involves carefully considering various components to ensure optimal functionality, comfort, and longevity. Key elements such as the major connector, clasp, rest, minor connectors, and denture base each play a specific role in achieving stability and retention. At present, design principles are based on the metal RPDs design; however, for newer materials like polymers, the design guidelines are still evolving through clinical practice and have not yet been officially documented in the literature.

Major connector in a RPD is a critical component that unites the different parts of the prosthesis, ensuring stability, support, and proper distribution of forces. Major connectors must be rigid to distribute forces evenly, thin yet strong to provide comfort, cover minimal tissue to avoid interference with speech and mastication, and be biocompatible to prevent adverse reactions (Akl & Stendahl, 2022; Phoenix et al., 2003). Rigid framework materials, such as CoCr or titanium alloys are traditionally favoured because they may transmit functional forces to the contralateral arch while minimising concentrated forces on the abutment teeth (Akl & Stendahl, 2022).

Advancements in material science have introduced polymers as viable alternatives, leading to design changes. Modern polymer such as nylon-based polymers, acrylic resins, aryl ketone polymer (AKP) and PEEK, offer more flexibility, requiring careful design to ensure adequate support and stability (Gray et al., 2021). Polymer-based major connectors are generally bulkier to compensate for the lower strength and rigidity compared to metals, affecting the overall design and necessitating a balance between bulk and patient comfort (Akl & Stendahl, 2022; Gray et al., 2021). Nevertheless, it is lighter than metals, enhancing patient comfort, particularly in maxillary RPDs.

The clasp assembly is another crucial component, responsible for retaining the RPDs on the abutment teeth. Clasp design must balance retention, bracing, and reciprocation forces while minimizing abutment tooth damage (Campbell et al., 2017). Traditional cast clasps have long been the standard choice, providing reliable retention through direct engagement with the tooth undercuts (Nishiyama et al., 2020). While polymer clasps generally have larger dimensions than traditional CoCr clasps, they can engage deeper undercuts (up to 0.50 mm compared to the 0.25 mm of CoCr clasps). This allows for the use of shorter clasps, enabling the clinician to design more discreet

clasps, which is particularly advantageous for creating less noticeable clasps in the anterior region of the mouth. However, while offering improved aesthetics, due to the tooth-coloured clasps it may be less retentive and provide less rigid bracing compare to traditional metal clasps (Akl & Stendahl, 2022; Gray et al., 2021).

Rest seats and rests are required to distribute functional forces to the abutment teeth and maintain RPD stability as it helps in directing occlusal forces along the long axis of the abutment teeth, reducing the risk of harmful lateral forces that may cause tooth mobility or damage. Proper design and placement of rest seats, including adequate size and shape, are important to prevent dislodgement and damage to the abutment teeth (McCracken, 2004; Phoenix et al., 2003). Additionally, the abutment teeth must be carefully evaluated for their ability to withstand the functional loads transferred by the RPD (Dula et al., 2015). Other key components, such as the minor connector, are influenced by the material choice. Traditional CoCr frameworks are stronger and more rigid, allowing for slimmer and more compact minor connectors while polymer-based RPDs requiring bulkier minor connectors to compensate for their lower rigidity. As current RPD design principles are based on metal frameworks, it is essential to adapt and refine key design parameters such as connector thickness, clasp geometry, and rest seat dimensions to suit the distinct mechanical properties of polymer-based frameworks.

2.4 Stress Distribution of RPDs on Abutment Teeth

Abutment tooth is a tooth that supports and retains RPDs. Abutment tooth with sound enamel surfaces is considered a fair risk for use as RPDs abutments. (Phoenix et al., 2003). RPDs can exert significant biomechanical stress on abutment teeth due to the direct forces applied during mastication. Terminal abutment teeth, located at the boundary of the prosthesis, often experience concentrated forces, leading to uneven stress distribution. This can result in excessive loading, causing biomechanical issues such as increased tooth mobility, tilting, or even tooth loss (Dula et al., 2015).

Ensuring proper stress distribution between the RPD and abutment teeth is crucial for minimizing the risk of damage or displacement of both the denture and abutment teeth. When functional occlusal stress is applied to the distal-extension RPD cases, a rotational movement typically occurs around the fulcrum of the terminal abutments' teeth. This reduces denture functionality, induces patient discomfort and

damage denture's supporting tissues (Igarashi et al., 1999). A good denture design must inhibit this rotary movement to protect the abutment teeth as well as residual ridge. It is important to note that supporting and retentive elements prepared on the abutment tooth should follow the established guidelines. This allows occlusal force to be directed towards the long axis of the tooth.

The number and location of abutment teeth can affect the distribution of stresses on the remaining teeth and other supporting structures (Knezović et al., 2002). More abutment teeth can distribute the load more evenly and reduce the risk of damage to the remaining teeth and tissues. Teeth with poor support or structural integrity (such as presence of decay, gum disease, or root canal treatment) may not be able to withstand the forces of RPDs and may require additional support or restoration (Piwowarczyk et al., 2007).

Besides, the occlusion of the patient can affect the distribution of stresses on the abutment teeth and the supporting structures of the jawbone and gums. An imbalanced or uneven bite can cause excessive stresses on certain areas of the denture and the supporting structures, leading to discomfort or pain. Occlusal forces can lead to denture movement, which may cause harmful shifting of the abutment teeth through the occlusal rest of the direct retainer (Mizuuchi et al., 2002; Ogata & Shimizu, 1991).

Additionally, the fit of the denture base and framework, along with the morphology of the residual ridges, plays a crucial role in the stability and movement of distal-extension RPD (Bural Alan, 2024). Apart from well-designed denture, a properly fitting denture base can help distribute occlusal forces more evenly, minimizing stress on the remaining teeth and surrounding tissues, thereby reducing the risk of potential damage. Support for both bilateral and unilateral distal-extension RPDs is shared between the abutment teeth and the edentulous ridges, which each contribute differently to the denture's stability (Bural Alan, 2024; Jiao et al., 2009). Understanding and optimizing this balance between support from the abutment teeth and edentulous ridge are essential for improving RPD performance, ensuring long-term comfort, and protecting the integrity of the remaining oral structures.

2.4.1 Evidence from Previous Studies on the Effect of RPDs on Abutment Teeth

Abutment teeth supporting RPDs are subjected to both mechanical and biological stress. Mechanical stress, arises from the forces exerted during chewing and

biting, which are transferred through the RPD framework to the abutment teeth. These forces can lead to tooth mobility, potential fracture, or damage to the supporting tissues, particularly when the denture is not well-designed or fit (Tada et al., 2015). Biological stress on abutment teeth refers to the increased risk of caries, periodontal disease, and plaque accumulation caused by the presence of the RPD which can interfere with natural oral hygiene and the self-cleaning action of the teeth. (Mine et al., 2009). Both types of stress contribute to the long-term wear and failure of abutment teeth.

Beyond these biomechanical and biological considerations, periodontal health has emerged as a central determinant of RPD success. A recent bibliometric analysis of 458 studies published between 1948 and 2024 revealed that periodontal considerations of abutment teeth remain a dominant research theme, despite a modest annual growth rate of 2.39% (Hamid et al., 2025). Significant and influential studies have consistently emphasized parameters such as probing pocket depth, gingival index, and tooth mobility as critical markers of abutment health (Hamid et al., 2025).

2.4.1.1 Mechanical Stress on Abutment Teeth in RPD Wearers

Mechanically, occlusal forces and denture movement can impose jiggling forces on periodontal tissues, potentially leading to abutment tooth failure. Nevalainen et al. found that direct abutments had a significantly higher risk of tooth loss compared to indirect abutments, while Tada et al. reported 5-year survival rate for abutment teeth (86.6%) is notably lower than for non-abutment teeth (95.8%) (Tada et al., 2013; Nevalainen et al., 2004). In addition to abutment type, other significant risk factors influencing survival include endodontic therapy, occlusal support, probing pocket depth, and crown-root ratio (Tada et al., 2013). This is in line with the recent systematic review and meta-analysis study that revealed that loss of non-vital abutment teeth are threefold higher for non-vital abutment teeth (Oh et al. 2021).

Bilateral and unilateral distal-extension RPDs distribute support between the abutment teeth and the edentulous ridge, however inadequate support can exacerbate mechanical loading on the abutments. Tada et al. emphasized the importance of bilateral occlusal support, particularly from premolars, in maintaining occlusal stability and minimizing excessive load on abutments (Tada et al., 2013). Occlusal instability, often caused by a reduction in the number of remaining teeth providing support, significantly increases stress on the abutment teeth.

2.4.1.2 Biological Stress on Abutment Teeth in RPDs Wearer

Beyond mechanical stress, abutment teeth in RPD wearers face increased biological challenges, including higher risks of plaque accumulation, periodontal inflammation, and caries (Akaltan & Kaynak, 2005; Mine et al., 2009). Studies consistently report elevated plaque indices, deeper periodontal pockets, and greater gingival inflammation around abutment teeth compared to non-abutments teeth (Müller et al., 2013; Yusof & Isa, 1994). These effects are often confined around clasp areas, where restricted self-cleansing promotes plaque retention (Shimura et al., 2010). Long-term studies indicate that abutment teeth are lost more frequently than non-abutments (26.4% vs. 14.2% over 10 years) and have higher mobility (Kern & Wagner, 2001).

Caries risk is also significantly greater, with estimates suggesting up to a six-fold increase in RPD wearers (Budtz-Jørgensen & Isidor, 1990), largely due to elevated levels of cariogenic bacteria such as *Streptococcus mutans*, *Streptococcus sobrinus*, and *Lactobacilli*, potentially due to new niches created by the denture surfaces (Mihalow & Tinanoff, 1988; Rocha et al., 2003). Although some microbiological studies report minimal changes in subgingival composition (Vanzeveren et al., 2002), increased plaque and gingivitis scores are well documented (Budtz-Jørgensen & Isidor, 1990). Importantly, evidence shows that meticulous oral hygiene and regular professional maintenance can mitigate these risks with patients attending periodic recall appointments demonstrate fewer new carious lesions and improved periodontal health (Tada et al., 2015).

2.4.1.3 Bibliometric Insights into Periodontal Considerations of Abutment Teeth

Research specifically focusing on the periodontal health of abutment teeth has shown a steady annual growth rate of 2.39%, emphasizing that the long-term success of RPDs is fundamentally tied to the biological stability of these supporting structures (Hamid et al., 2025). Highly cited clinical studies, which represent the gold standard in this field, prioritize the evaluation of critical periodontal variables including probing pocket depth (PPD), clinical attachment level (CAL), tooth mobility, the plaque index, and the gingival index to assess abutment integrity. Bibliometric mapping revealed nine research clusters that define the thematic structure of periodontal health studies in relation to RPDs (Figure 2.1). Among these, clusters associated with biomechanical

evaluation, material development, and periodontal monitoring provide important context for understanding the combined effects of mechanical and biological stresses on abutment teeth. For instance, finite element analysis (FEA) emerged as a key research theme, emphasising its role in simulating stress distribution on abutment teeth under different RPD designs and materials (Hamid et al., 2025). Such computational approaches aim to minimize concentrated forces that could lead to abutment overload and mobility, supplementing clinical strategies to reduce mechanical stress.

Material-related clusters highlight increasing attention to PEEK and other thermoplastic resins as alternatives to CoCr frameworks. These materials are associated with improved stress distribution and reduced plaque retention, indicating their potential to alleviate both biomechanical and biological risks (Akl & Stendahl, 2022). Keyword mapping also identified high-impact terms such as “longitudinal study”, “Periotest”, and “PEEK”, reflecting the emphasis on long-term periodontal monitoring and material innovations to enhance abutment integrity (Hamid et al., 2025). Additionally, terms like “periodontal diseases” and “risk factors” rank among the most frequently cited, reinforcing the importance of preventive strategies in maintaining abutment health. Overall, these bibliometric insights align with clinical evidence on mechanical and biological challenges, highlighting a research trend that integrates predictive modelling, advanced materials, and diagnostic technologies to protect periodontal health and optimize the prognosis of abutment teeth in RPD treatment.

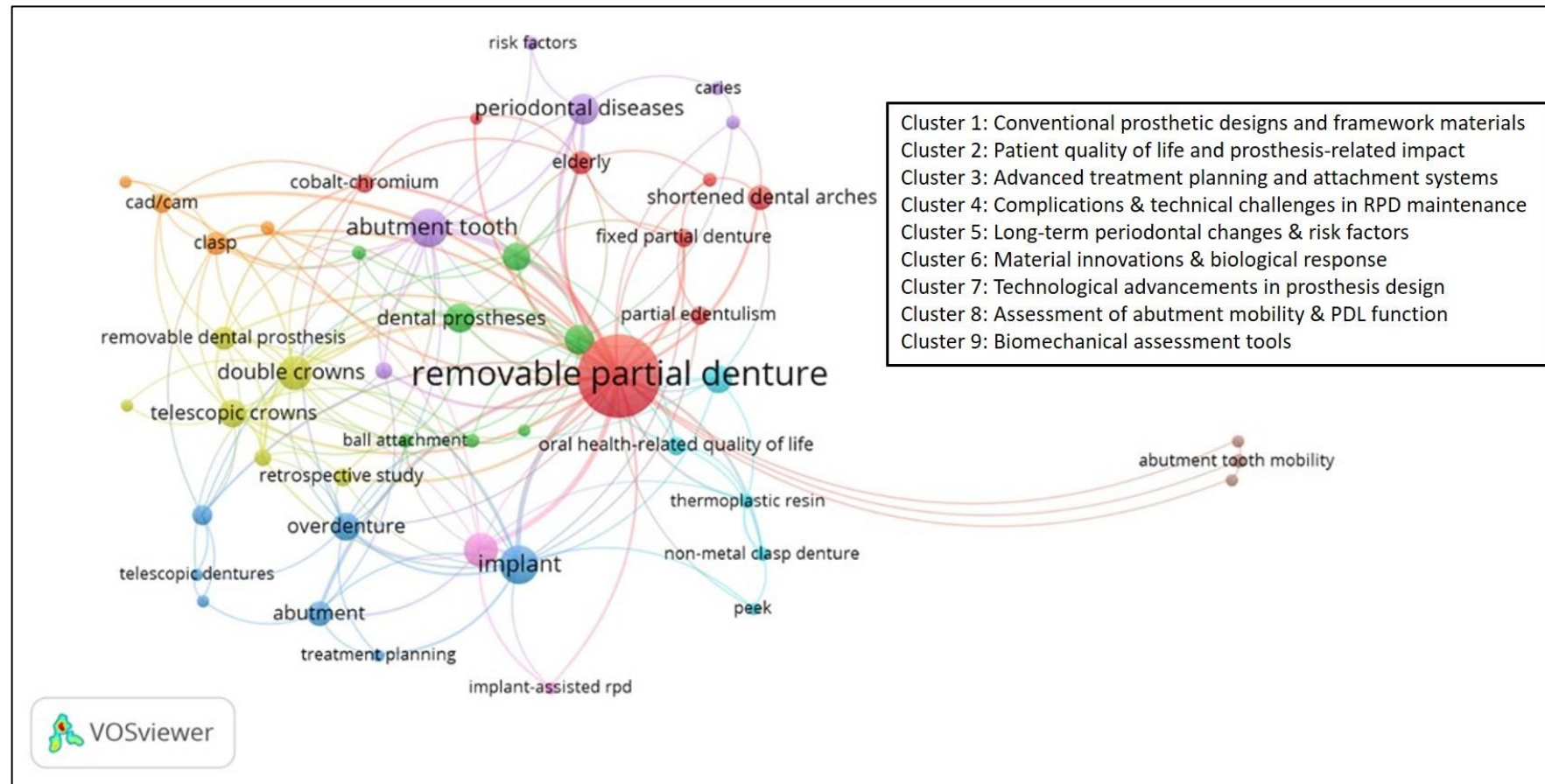


Figure 2.1 Network Visualization of Keyword Occurrences based on the Authors' Keywords, Displaying 48 Items Grouped Into Nine Distinct Clusters.

Adopted from Hamid et al., 2025

2.5 Material for RPDs Framework

Conventional RPDs frameworks are widely classified as metal-based frameworks and polymer-based frameworks (Figure 2.2). Currently, CoCr or titanium are the materials of choice for RPD frameworks. Historically, all metal-based frameworks have been manufactured with type IV gold alloy (Al Jabbari, 2014; Wataha, 2002). However, since the mid-1930s, when CoCr alloys were introduced, their use in RPDs has been widespread due to the rising cost of noble metals (Al Jabbari, 2014). CoCr alloys consist of cobalt (60–65%), chromium (27–30%), and molybdenum (5–6%) along with traces of other metals (Al Jabbari, 2014). Co serves as the principal component, whereas Cr and Mo are the principal alloying elements. Cr is added to boost the material's resistance to corrosion and oxidation by promoting carbide formation and solid solution strengthening (Al Jabbari, 2014). By creating finer grains, the addition of Mo to the alloy increased its mechanical strength (solid-solution strengthening) and its corrosion resistance (Akl & Stendahl, 2022). These alloys have a relatively high elastic moduli and low densities, in addition to being significantly stronger and harder than the type IV gold-based alloys (Craig & Powers, 2002; Wataha, 2002). These properties allow the framework to be developed thinner, lighter, and stronger than Type IV gold alloys, hence further discouraging the use of type IV gold alloys for RPDs fabrication (Wataha, 2002).

Commercially pure (CP) titanium and titanium alloys have been utilised to make RPD frameworks for the past 20 years due to their biocompatibility, good corrosion resistance, and equivalent mechanical qualities to gold alloys such as ductility, low thermal conductivity, and hardness (Ahmed et al., 2021; Al Jabbari, 2014; Wataha, 2002). Titanium's low density enables lightweight prostheses. Despite advances in titanium lab technology, numerous cast titanium framework limitations persist (Ohkubo et al., 2008; Okabe et al., 1998). Burn-out is slow, castability and machinability are poor, reaction layer on cast surface, polishing is difficult, and starting expenses are high compared to other metals (Ahmed et al., 2021; Craig & Powers, 2002).

Although CoCr is often considered the best material for an RPD framework, its physical attributes are not optimal. Metal clasps that are unsightly, increased prosthesis weight, the possibility of metallic taste, oral galvanism, abutment tooth osteolysis, biofilm generation, and allergic reactions to metals are all common downsides of metal-based frameworks (Akl & Stendahl, 2022; Campbell et al., 2017; Mori et al., 1997).

Due to the limits of metal-based frameworks, the use of metal-free materials such as high-performance polymers such aryl-ketone polymers (AKP) (Luemkemann et al., 2020; Marie et al., 2019), and PEEK (Harb et al., 2019; Muhsin et al., 2018; Refai et al., 2022) has been investigated. AKP have the ability to engage and disengage undercuts without exceeding their elastic limit (Luemkemann et al., 2020). PEEK is a new material used in RPD frameworks. This material has anti-allergic properties, easy to clean, has a low plaque affinity, and has sufficient wear resistance (Akl & Stendahl, 2022; Muhsin et al., 2018).

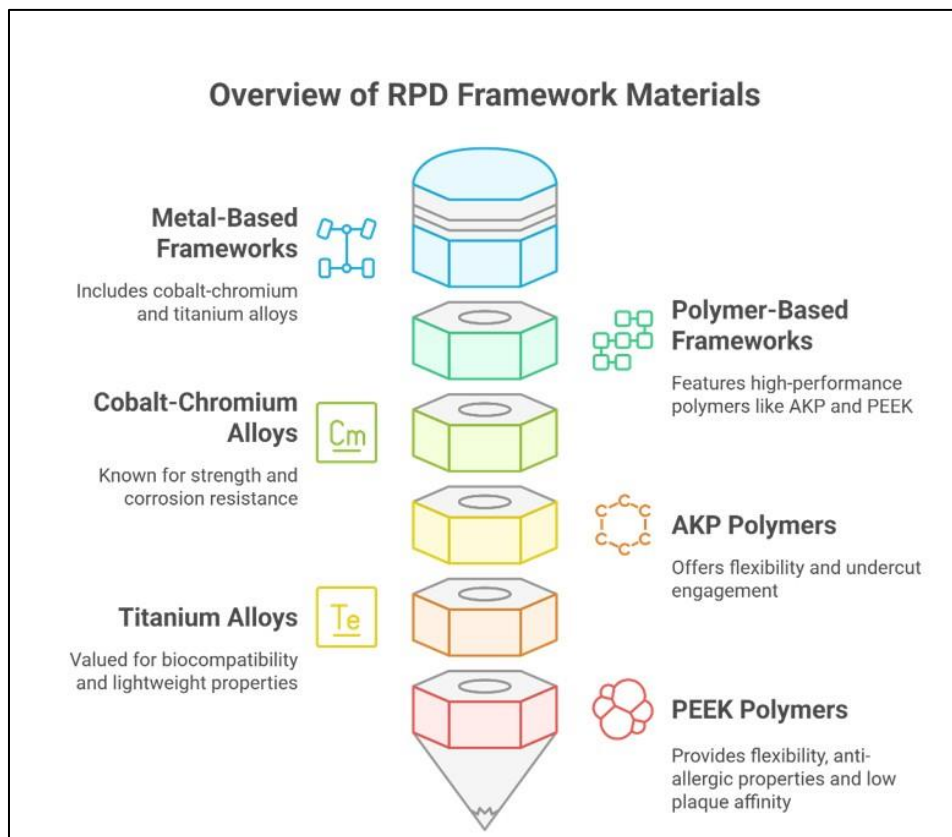


Figure 2.2 Overview of RPD Framework

2.6 Poly-ether-ether-ketone (PEEK)

Poly- ether-ether-ketone (PEEK) is a high-impact thermoplastic polymer and a member of the poly-aryl-ether-ketone (PAEK) family. The use of PEEK has become increasingly more common in dental practise due to its superior physical, chemical and mechanical properties as well as its good biocompatibility and low plaque affinity. PEEK is strongly recommended for patients with allergies as alternative to metal alloys

and currently widely used as dental implants, orthodontic brackets, fixed prostheses, and RPDs framework (Papathanasiou et al., 2020; Najeeb et al., 2016). Two bibliometric analyses of prosthodontic literature demonstrated a significant rise in PEEK-related citations over the past decade, with ‘PEEK’ ranking as a high-impact term, indicating its emergence as a material of growing interest in RPDs (Hamid et al., 2024; Hamid et al., 2023).

2.6.1 Composition of PEEK

PEEK is a linear, aromatic, thermoplastic, semi-crystalline polymer with the chemical structure $(-\text{C}_6\text{H}_4-\text{O}-\text{C}_6\text{H}_4-\text{O}-\text{C}_6\text{H}_4-\text{CO}-)$ (Qin et al., 2021). Figure 2.3 illustrates the chemical structure and chain packing of PEEK. As a semi-crystalline material, it consists of both crystalline and amorphous regions within its structure. Figure 2.4 showing the tightly packed, ordered crystalline zones interspersed with disordered, randomly oriented amorphous regions. The crystalline regions contribute to the material’s strength and stiffness, while the amorphous regions enhance its flexibility and toughness. This unique combination results in favourable mechanical properties, including a relatively high modulus of elasticity compared to fully amorphous materials (Zol et al., 2023; Akl & Stendahl, 2022).

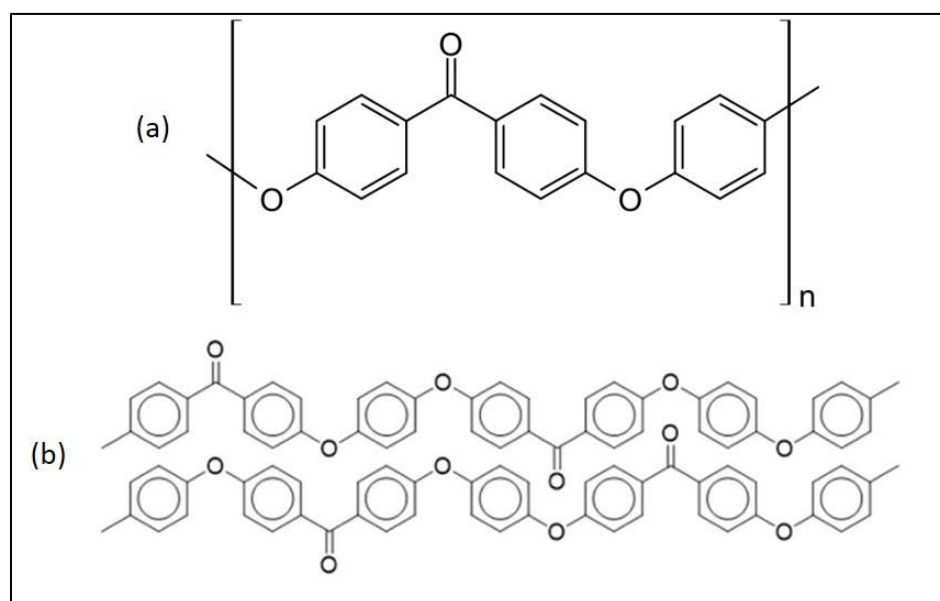


Figure 2.3 a- Chemical Structure of PEEK b- Chain Packing of PEEK.

Adopted from Zol SM, et al., 2023

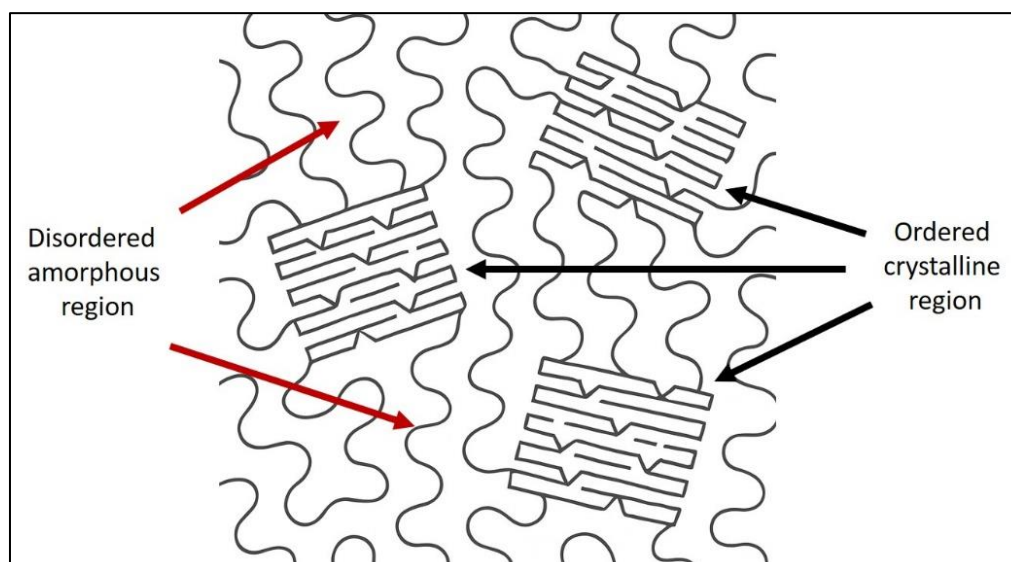


Figure 2.4 Schematic Diagram Showing Ordered Crystalline Region and Disordered Amorphous Region in PEEK.

Imaged adapted from pocketdentistry.com and figure newly generated by the author

2.6.2 PEEK Forms for Dental Use

The most common formulations of PEEK used in dentistry are either unfilled, pure 100% PEEK (such as JUVORA™) or modified PEEK material such as 80% PEEK with 20% nanoceramic filler (such as BioHPP), 80% PEEK with 20% titanium dioxide filler (such as Dentokeep disc), or 80% PEKK with 20% filler including titanium dioxide (such as Pekkton®) (Table 2.1).

Table 2.1
Summary of Commercialize Brand of PEEK Materials in Market for Dental Use

Trade Name	Manufacturer
PEEK OPTIMA	Invibio, United Kingdom
JUVORA™ PEEK	Invibio, United States
Dentokeep PEEK Disc	NT-Trading, Germany
Bio High Performance Polymer (BioHPP™)	BreCAM, Bredent, Germany

The material modification includes the addition of ceramic fillers with grain sizes between 300 and 500 nm, which act more as pigments and surface topography influencers and are not likely to give significant reinforcing properties to the material

since they are not fibres (Alqutaibi et al., 2025). Nevertheless, according to the manufacturer, the small grain size of filler also contributes to homogeneity and improved polishing properties, and 20% filler will make the material stiffer, which will consequently also slightly increase its brittleness (Alqutaibi et al., 2025; Alexakou et al., 2019). One of the commercial brands of PEEK that represent modified PEEK material with enhanced properties on the market for dental use is PEEK Optima, which adds carbon fibre to increase the elastic modulus and improve properties such as hardness and creep resistance (Schwitalla et al., 2015).

2.6.3 Bibliometric Insights on PEEK in RPDs

To track the development of research priorities in prosthodontics, a bibliometric assessment of RPD-related publications from 2012 to 2022 was carried out, highlighting shifts in key topics and emerging trends within the field (Hamid et al., 2024). The trend topic visualization represents the chronological evolution of research themes, where the position of each bubble corresponds to the year of prominence and its size represents the frequency of the associated keyword. In this analysis, PEEK emerged as a significant trend topic around the year 2021, indicating growing attention within the field (Figure 2.5). Further analysis using overlay visualization identified PEEK as a high-impact keyword, characterized by an average citation count of 34.7 and an average normalized citation score of 3.07 (Figure 2.6). The average citation is the total number of citations a paper receives divided by the number of papers, whereas the average normalized citation is the citation count of a paper adjusted for differences in citation practices across fields, years, and document types, allowing for fair comparisons (van Eck & Waltman, 2011). These values indicate that publications focusing on PEEK achieved significantly higher academic visibility compared to other keywords in prosthodontics, reinforcing its emergence as a key research area within the field (Hamid et al., 2025). Furthermore, an evaluation of keyword trends across five-year intervals (2018–2022) validated PEEK's constant significance as an evolving research focus in RPD studies (Figure 2.7). This trend highlights the growing interest in polymer-based frameworks as practical alternatives to traditional CoCr alloys, largely attributed to their favourable mechanical performance, superior biocompatibility, and promising clinical applicability (Akl & Stendahl, 2022).

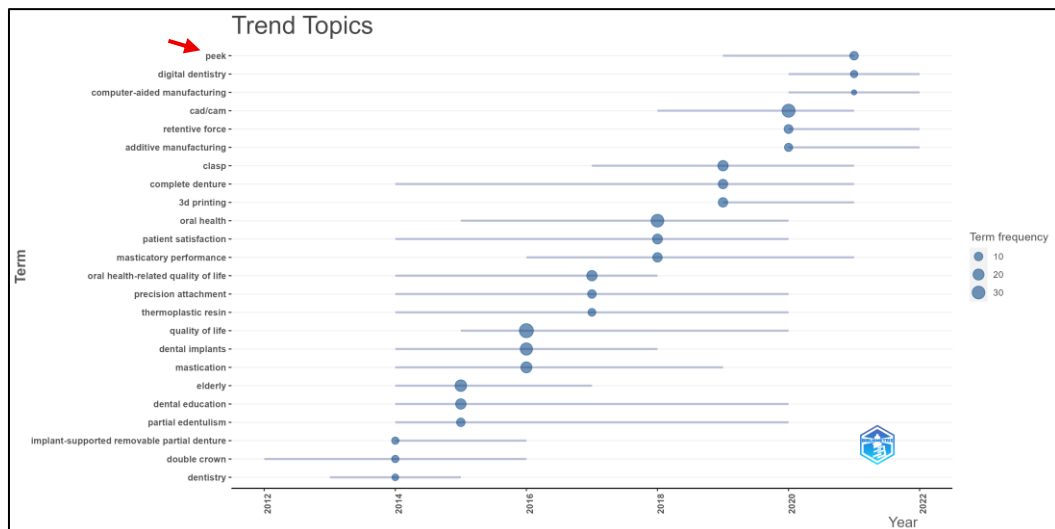


Figure 2.5 Timeline of Trend Topics in RPD Research between 2012 and 2020. Emerging Topic PEEK (Polyetheretherketone) Appeared around 2020–2022 (Indicated by Red arrow at the top)

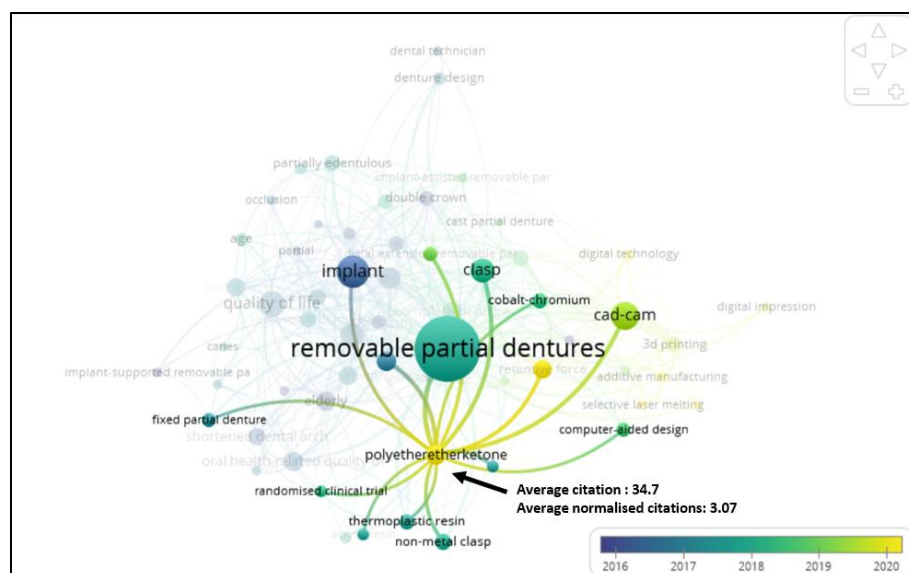


Figure 2.6 Overlay Visualization Illustrating the Prominence of 'PEEK' as a High-Impact Keyword in Prosthodontics Literature from 2012 to 2022, with an Average Citation of 34.7 and an Average Normalized Citation Score of 3.07

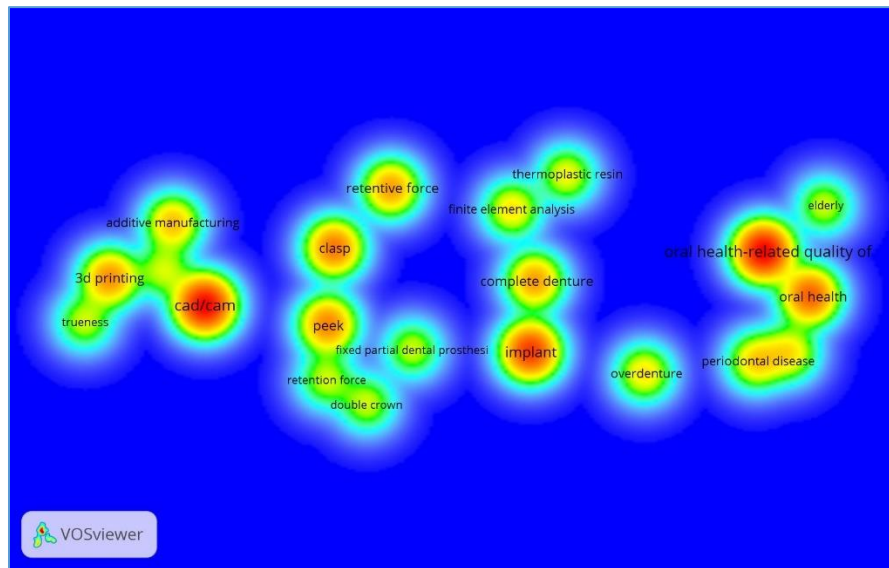


Figure 2.7 PEEK was Identified as Emerging Research Focus Within Removable Partial Denture (RPD) Studies During the Period 2018–2022, Reflecting Increasing Academic Interest in Polymer-based Frameworks as Alternatives to Traditional Metal Alloys

2.7 Fabrication Processes of RPDs

Traditionally, lost-wax casting is used to fabricate RPDs frameworks (Phoenix et al., 2003). However, additional laboratory procedures such as cast duplication and investment are considered a time-consuming and prone to error (Akl & Stendahl, 2022). In order to overcome these limitations, digital fabrication methods using computer-aided designing-computer aided manufacturing (CAD/CAM) technology are introduced (Tamimi et al., 2020; Campbell et al., 2017; Williams et al., 2006). With the new technology, the cast digitization can be done either using intraoral or extraoral laboratory scanners followed by frameworks design using the specialized CAD software. This followed by the CAM process which either can be subtractive or additive manufacturing (Pereira et al., 2021; Tamimi et al., 2020). In general, subtractive manufacturing is more effective for polymer-based framework such as PEEK while additive techniques are mainly indicated for metal-based framework such as CoCr and titanium (Tamimi et al., 2020). As the subtractive or milling manufacturing of metal-based framework is difficult, stereolithography printing of wax or resin patterns for casting of metal-based framework is more preferable. Previous systematic review had indicated that fit accuracy of RPDs framework fabricated by digital (either CAD/CAM and rapid prototyping) techniques was superior as compared to the conventional

techniques (Ahmed et al., 2021). Apart from accuracy, fast and reduce human error, digital technique can save design for future use.

2.7.1 Fabrication Process of PEEK RPDs Framework

PEEK available for dental and medical purposes as granules to be pressed and blank disks (Figure 2.8). PEEK-based prostheses can be manufactured in a variety of ways, such as traditional lost-wax casting in combination with injection moulding, subtractive manufacturing (CAD/CAM milling) and additive manufacturing (3D printing).



Figure 2.8 PEEK CAD/CAM Dental Disc. Courtesy of Invisio, United Kingdom

2.7.1.1 Lost-wax Technique and Injection Moulding

The traditional lost-wax technique, combined with injection moulding, has been widely used to fabricate PEEK frameworks. In this method, PEEK granules are heated to a molten state and injected into a mould under high pressure, adopting the shape of the wax pattern. After cooling and solidification, the framework is removed and polished (Sinha et al., 2017; Zoidis et al., 2016). While this technique is well established, it is highly technique-sensitive and requires precise control of mould temperature, particularly for semi-crystalline polymers such as PEEK. Variations in temperature distribution can lead to inconsistent mechanical properties or defects in the final product (Muhsin et al., 2019). Moreover, this analogue method lacks the adaptability and efficiency offered by digital workflows, which are increasingly favoured in contemporary dental laboratories.

2.7.1.2 Subtractive Manufacturing or CAD/CAM Milling

Subtractive manufacturing, or CAD/CAM milling, is a digital manufacturing method that enhances precision and reproducibility. The workflow begins with either a direct intraoral scan or an indirect scan of an impression, followed by digital design using specialized software. The framework is then milled from a solid PEEK blank using a 5-axis computer numerical control (CNC) milling machine (Russo et al., 2021; Negm et al., 2019). This approach allows for the use of preformed PEEK discs with thicknesses tailored to clinical needs (10–30 mm), and the multi-axis capability ensures high accuracy in complex geometries (Alghazzawi, 2016). However, while milling yields precise fits, it generates significant material waste and incurs high equipment costs. Additionally, limited aesthetic customization and the potential for microcracks during milling pose challenges. Thus, its use may be best suited to cases that prioritize fit and mechanical performance over aesthetics.

2.7.1.3 Additive Manufacturing or 3D Printing

Additive manufacturing offers a paradigm shift in prosthesis fabrication by building objects layer by layer based on Standard Triangulate Language (STL) files generated from digital scans (Zol et al., 2023). Its primary advantage lies in its design flexibility and material efficiency, especially when compared to subtractive techniques (Haleem & Javaid, 2019). However, the application of additive manufacturing in PEEK RPDs remains limited due to the high processing temperatures required and current technological constraints in achieving adequate interlayer bonding. As such, hybrid workflows where a 3D-printed resin pattern is subsequently processed using traditional techniques are still common (Negm et al., 2019). Although promising, fully additive manufacturing of PEEK frameworks remains in early development, and further advances in printer capabilities and material handling are needed before widespread clinical adoption.

2.7.1.4 Conclusion on Fabrication Process of PEEK RPDs Framework

A systematic review by Chaturvedi et al. (2024) found that among digital fabrication methods, milling of PEEK offers the best fit accuracy (Chaturvedi et al., 2024). In contrast, while 3D printing shows promise, it still faces technical challenges particularly with high-performance polymers like PEEK, which require elevated processing temperatures and exhibit interlayer bonding issues. Milled PEEK frameworks demonstrated superior fit accuracy and minimal distortion, outperforming both conventional lost-wax techniques and several additive manufacturing methods.

Additive techniques such as selective laser melting (SLM), commonly used with metals, have produced accurate outcomes (Peng et al., 2022). However, their application to polymers such as PEEK remains limited due to the material's high processing demands. Although additive manufacturing offers benefits such as design flexibility and reduced material waste, CAD/CAM milling remains the preferred technique for fabricating PEEK frameworks in clinical contexts that demand mechanical durability and precise fit.

Currently, there is no conclusive evidence that 3D printing outperforms milling for definitive RPD frameworks made of PEEK. However, it holds future potential as the technology advances. The systematic review suggests that while no single method is universally superior, CAD/CAM milling currently provides the most reliable results for fabricating PEEK RPD frameworks (Chaturvedi et al., 2024). Its superior mechanical strength and fit accuracy make it more suitable for long-term clinical use. In contrast, additive manufacturing, despite its advantages in material efficiency and design flexibility, remains more appropriate for provisional applications until its mechanical limitations are resolved.

Characteristic	Lost-Wax & Injection Moulding	Subtractive Manufacturing (CAD/CAM Milling)	Additive Manufacturing (3D Printing)
 Process	Molten PEEK injected into mould	Milled from solid PEEK blank	Layer-by-layer construction from STL files
 Precision & Accuracy	Technique-sensitive, dependent on temperature control	High accuracy due to CNC milling	Limited by interlayer bonding and processing temperatures
 Material Efficiency	Moderate, some material waste	Significant material waste	High material efficiency
RM Cost	Well-established, lower equipment costs	High equipment costs	Evolving, potentially lower material costs
 Design Flexibility	Limited by mould design	High accuracy in complex geometries	High design flexibility
 Suitability	Suitable for simple frameworks	Best for fit and mechanical performance	More appropriate for provisional applications

Figure 2.9 Comparison of Conventional (Lost-wax, Injection Moulding) Versus Digital (Subtractive Milling, Additive 3D printing), Highlighting Differences in Process Workflow, Precision, Material Efficiency, and Others

2.8 Designing PEEK RPDs

Designing a PEEK RPD framework differs significantly from designing a CoCr framework owing to the contrasting material properties of the two materials. PEEK is a flexible, lightweight polymer, while CoCr is a rigid, durable metal alloy (Akl & Stendahl, 2022). These differences impact both the structural design and the clinical considerations for each framework type. Currently, there are no standardized design protocols for PEEK RPD frameworks, and their design principles are evolving based on clinical practice rather than formal documentation in the literature, leaving clinicians to rely on manufacturer instructions, case reports, and clinical studies for guidance.

For the major connector in PEEK RPD frameworks, manufacturer guidelines recommend a lingual bar with a minimum thickness of 2 mm and a vertical height of 5 mm (Figure 2.10). This dimension ensures adequate strength and durability while maintaining PEEK's flexibility, allowing it to adapt to oral contours and reduce stress on supporting tissues (Juvora Ltd., 2022). In contrast, CoCr frameworks typically

employ a similar thickness (around 2 mm) but may achieve sufficient rigidity with a slightly smaller height due to the alloy's higher strength and stiffness. No specific recommendations for a lingual plate design are currently available (Figure 2.11).

For clasp design, manufacturer guidelines for PEEK frameworks recommend a clasp thickness of 2 mm and a height of 3 mm (Juvora Ltd., 2022). Due to PEEK's inherent flexibility, the undercut requirements are less restrictive than those for CoCr. PEEK clasps can engage deeper undercuts up to 0.5 mm in the anterior region and 0.75 mm in the posterior region without exerting excessive pressure on the abutment teeth (Figure 2.11). This flexibility allows PEEK clasps to closely conform to the tooth surface, thereby enhancing both retention and comfort. In contrast, CoCr clasps typically engage shallower undercuts (around 0.25 mm) because the metal's rigidity could otherwise generate excessive forces on the abutment teeth, potentially causing discomfort.

Rest seat is essential in CoCr frameworks for providing occlusal support, preventing movement, and distributing forces evenly. However, rest seats are sometimes considered optional in PEEK framework, as PEEK's flexibility can reduce the need for rests by exerting less stress on the abutment teeth (Gray et al., 2021). Nevertheless, rest seats may still be recommended when additional support is required, particularly in situations involving high functional loads or stability concerns. Due to the slightly increased framework thickness required for PEEK, incorporating rest seats can be challenging in areas with limited occlusal space unless substantial tooth preparation is performed. In such cases, alternative design features positioned above the survey line may be used to provide tooth support and prevent vertical displacement of the prosthesis toward the tissues (Gray et al., 2021).

One significant drawback of PEEK clasps is that they cannot be adjusted post-fabrication due to their inability to bend, which highlights the need for meticulous preoperative design to ensure proper fit and retention from the outset (Ichikawa et al., 2019). This lack of adjustability means that any fit errors would likely require the framework to be remade rather than adjusted.



Figure 2.10 Example Schematic Diagram Showing the Minimum Design Requirements for a Lingual Bar in a PEEK-based Removable Partial Denture, based on Manufacturer Recommendations. The Diagram Illustrates a Minimum Width of 2 mm and a Minimum Thickness of 5 mm

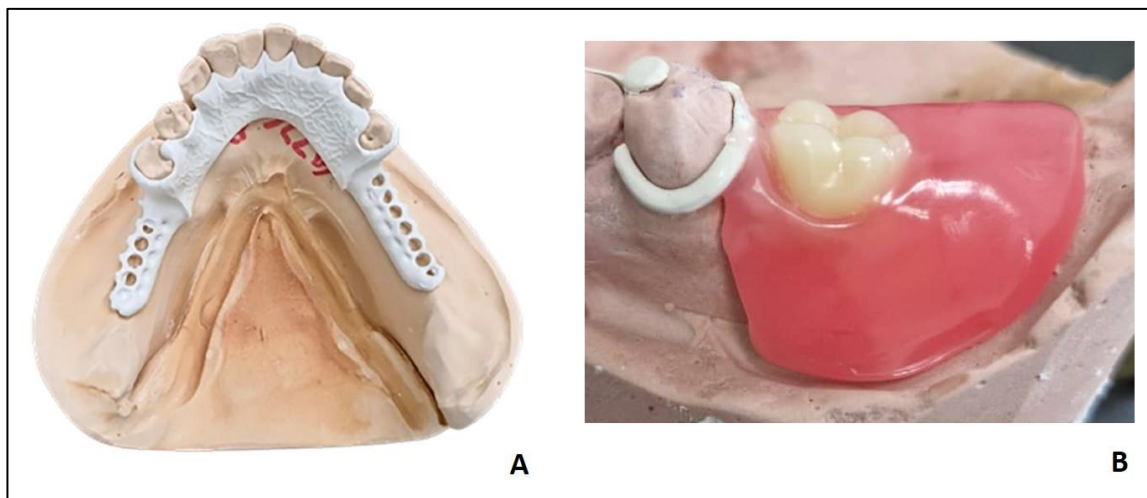


Figure 2.11 A. Example of a Lingual Plate Design for a Removable Partial Denture. No Design Specification was Mentioned by The Manufacturer. B. Clasps were Designed with a Minimum Width of 1.3 mm, using a 0.5 mm Undercut

2.9 Evidence from Case Reports and Clinical Studies

Evidence from case reports on PEEK RPD framework design provides valuable insight into clinical application, but also reveals a lack of standardization in denture design parameters. Table 2.2 summarizes case reports on RPDs fabricated from PEEK.

Of the eight case reports reviewed, five evaluated PEEK as a framework material, two integrated PEEK clasps into CoCr frameworks, and one focused on the repair of a PEEK clasp.

Across published case reports on PEEK RPD, authors commonly described the type of major connector used but rarely reported precise design dimensions, such as connector width or height. Zoidis et al. selected a lingual bar to improve resistance to torsional forces in distal extension cases, whereas Harb et al. and Wu et al. employed lingual plate connectors in PEEK frameworks, citing improved strength and clinical stability (Harb et al., 2019; Wu et al., 2022; Zoidis et al., 2016). However, none of these studies provided specific measurements for lingual plate dimensions. Similarly, more recent reports involving palatal bar and horseshoe palatal strap designs did not specify connector dimensions, highlighting a persistent lack of standardized reporting of RPD design parameters (Curinga et al., 2023a; Dakhli et al., 2023).

Regarding clasp design, only three studies reported the use of a 0.5 mm undercut for clasp engagement, demonstrating PEEK's flexibility in engaging deeper undercuts without excessive force (Dakhli et al., 2023; Harb et al., 2019; Zoidis et al., 2016). Harb et al., further suggested that increasing clasp bulk could enhance retention, although no studies reported precise clasp arm width or thickness (Harb et al., 2019). Ichikawa et al., observed that PEEK rest and clasp arm components maintained fit without deformation after two years of follow-up, but did not specify undercut depth, while other reports similarly omitted these details (Wu et al., 2022; Ichikawa et al., 2019). In addition, none of the reviewed studies described rest seat design, which may reflect either PEEK's inherent adaptability or inconsistent reporting practices. In conclusion, most case reports on PEEK RPDs lack detailed and standardized technical specifications for major connectors, clasps, and rest seats. The wide variation in prosthesis design, ranging from Kennedy Class I to Class IV cases, further limits direct comparison of framework and clasp design parameters across studies.

Table 2.3 provide detail summary on clinical studies related to PEEK materials in RPD. Twelve clinical studies were evaluated, encompassing diverse objectives, methodologies, and outcome measures. Most studies combined clinical assessments with patient-reported outcomes, including masticatory efficiency, periodontal health, retention, fit, and oral health–related quality of life (OHRQoL). Questionnaires used for patient-reported outcomes included validated instruments such as the Oral Health Impact Profile (OHIP), McGill Denture Satisfaction Questionnaire (MDSQ),

Satisfaction with Lower Removable Denture Questionnaire (SLRD-Q), and visual analog scales (VAS).

Only two studies reported detailed framework dimensions, which were adapted to compensate for PEEK's lower modulus of elasticity. Oliveira et al. increased framework thickness by 25% relative to CoCr by increasing the thickness of occlusal rests, clasps, minor and major connectors, and saddles, while adopting a 0.25 mm undercut similar to CoCr clasps (Oliveira et al., 2025). Hegazi et al. used an even greater thickness increase (up to 2.8 mm) and tapered Aker's clasps (from 2.0 mm at the origin to 1.0 mm at the tip) to improve rigidity. In contrast, most of the other studies did not specify RPD component dimensions, reflecting a lack of standardized design reporting that limits reproducibility and comparison across studies.

Clinical outcomes were the primary focus in most clinical studies. Three studies assessed fit and accuracy: two using conventional polyvinyl siloxane replicas (Maraka & Alaa'a Salloum, 2021; Yoon et al., 2024), and one employing digital 3D deviation mapping (Ge et al., 2025). All studies concluded that PEEK frameworks provided acceptable accuracy comparable to CoCr, with digital methods offering more precise and clinically relevant assessment.

A limited number of studies evaluated other clinical parameters. Lo Russo et al. evaluated dimensional changes in the residual ridges of patients wearing PEEK RPD frameworks compared with a control group of untreated patients, suggesting that PEEK may aid ridge preservation over a one-year period, with no significant changes in vertical height or three-dimensional morphology (Lo Russo et al., 2022). Oliveira et al. found CoCr frameworks provided better masticatory performance and stability than PEEK, though maximum bite force was similar (Oliveira et al., 2025). Only two studies addressed microbial adhesion, reporting mixed results regarding colonization by gram-positive cocci and *Candida*. Medappa observed increased surface irregularities and gram-positive cocci colonization after 24 hours of use without cleaning, whereas Mansour et al. reported greater *Candida* colonies on the denture surface of PEEK after four weeks (Mansour et al., 2020; Medappa, 2018).

Two studies assessed periodontal parameters and found no significant differences in periodontal outcomes (Zhai et al., 2025; Ali et al., 2020). Ali et al. evaluated plaque index, gingival bleeding index, and periodontal pocket depth, while Zhai et al. only focused on the gingival index and tooth mobility. Patient-centered outcomes, such as satisfaction and OHRQoL showed mixed results as some studies

reported higher comfort or aesthetics for PEEK (Zhai et al., 2025; Mohamed & Rasha, 2019), while other studies found comparable improvements between PEEK and metal frameworks over one to two years of review (Hegazi et al., 2025; Ali et al., 2020). Although most clinical studies evaluated retention through patient-reported outcomes, one study clinically measured retention force between PEEK and CoCr frameworks in Kennedy Class III using a digital force meter (Eldien, 2020). The study reported higher retention with CoCr compared to PEEK. Notably, the study employed a 0.25 mm undercut, although the manufacturer recommends 0.50 mm or 0.75 mm for optimal performance.

In summary, the available case reports and clinical studies indicate that PEEK frameworks are promising in terms of fit, weight reduction, comfort, aesthetics, and, in some cases, ridge preservation. However, findings on masticatory performance and satisfaction remain variable. Only three studies provided detailed, evidence-based framework dimensions, highlighting the need for standardized design guidelines. In most other studies, framework design has relied on manufacturer recommendations and clinician experience, with no standardized protocols reported. Future research should focus on long-term clinical studies with clearly defined component specifications to improve predictability and clinical success of PEEK RPDs. Despite these variations, all studies confirmed the overall clinical acceptability of both materials, suggesting that PEEK may be more suitable for patients prioritizing comfort and aesthetics, whereas metal frameworks remain beneficial when optimal stability is required.

Table 2.2
Case Reports Related to PEEK Material in RPDs

Author/ Year/ Indication of use	Participant characteristics	Materials/Fabrications	Author's remarks
He et al., 2025 Repair clasp	89 years old/female/ Kennedy Classification I modification 1	PEEK blank (BIOPAEEK; Dentex Inc) Scanner: AutoScan-DS-EX Pro; Shining 3D) Milling machine (Cameo N4; Aidite Technology Co, Ltd)	A chairside approach using CAD-CAM technology was employed to repair defective 5-year-old PEEK-based RPDs following the loss of an abutment tooth. The repaired PEEK clasp was redesigned with increased thickness to enhance durability. Design: No details on clasp thickness and undercut were provided
Dakhli et al., 2023 Framework	58 years old/male/ Kennedy Classification III	PEEK dental disk No details were provided regarding the scanner or milling machine used.	Emphasize in the PEEK's low weight that allows for lighter prostheses that enhance patient comfort and satisfaction during function, although its fabrication cost is higher than that of conventional denture. Design: "Horse-shoe" palatal major connector, cingulum rest, Aker clasps using 0.5 mm undercut
Curinga et al., 2023a Framework	72 years old/female/ Kennedy Classification III modification 1	OverPeek (Celmat, São Paulo, Brazil) 3D printer: Anycubic Photon Mono X4K SLA/LCD 3D printer (China) Curing machine: Anycubic, Shenzhen, China	A case report evaluated patient satisfaction, comfort, retention, number of follow-up visits, masticatory performance, and quality of life after wearing 3D printing PEEK and CoCr dentures in a 15 days crossover design, but the assessment was limited to a single patient. Design: Palatal bar with Aker clasp with no details design specification
Wu et al., 2022 Framework	53 years old/ female/ Kennedy Classification IV	PEEK disk (BioPAEK, Sino-dentex Co., Ltd., Changchun, China) Scanner: TRIOS 3, 3Shape (Denmark) Milling machine: Cameo, Aidite (Qinhuang DAO) Technology Co., Ltd., Qinhuangdao, China)	PEEK was used as the RPD framework, with an initial 3D-printed diagnostic denture (separable into dentition and base with framework) serving as the prototype. The detachable portion was later replaced with a milled PEEK framework combined with a thermoplastic base using compression molding for the definitive RPD. Design: Lingual plate, occlusal rest and cingulum rest but did not mention on clasp undercut

Author/ Year/ Indication of use	Participant characteristics	Materials/Fabrications	Author's remarks
Htun et al.,2020 Clasp	25 years old/ female/ Kennedy Classification III modification 1	No details provided	Incorporated clasp assembly in CoCr RPD. Over a 6-month follow-up period, no clasp deformation or changes were observed, and no signs of gingivitis or periodontitis were detected in relation to the abutment teeth. Design: No specific design details were provided
Harb et al., 2019 Framework	56 years old/ female/ Kennedy Classification I	Material: PEEK discs (Ceramill PEEK, Juvora Ltd., Lancashire, UK) Scanner: 3D scanner (Ceramill Map400) and CAD software (3Shape Dental System; 3Shape) Milling machine: Ceramill Motion 2; Amann Girrbach	When using PEEK as the RPD framework material, strategically designed clasps engaging a 0.5 mm undercut and incorporating increased bulk can substantially improve retention in clinical application. Design: Lingual plate, occlusal rest and cingulum rest with clasps engaging at 0.5 mm undercut
Ichikawa et al., 2019 Clasp	84 years old/ female/ Kennedy Classification I	PEEK dental discs (Ceramill PEEK,Juvora Ltd., Lancashire, UK) Scanner: CAD software (Geomagic Freeform, USA) Milling machine: RXP500 DSC	Incorporated PEEK clasp into RPD, non-filler PEEK was employed as the clasp material for the RPD, with both the clasp arm and remaining framework components maintaining excellent fit and showing no deformation even after a two-year follow-up. Design: No details specification on clasp design and did not mention on clasp undercut
Zoidis et al., 2016 Framework	70 years old/ female/ Kennedy Classification I	Material: BioHPP; Bredent GmbH, Senden, Germany Technique: Conventional lost wax technique using a vacuum press device (2 press; Bredent GmbH)	Despite its advantages, PEEK should not be considered a direct substitute for a well-designed CoCr RPD framework, as current clinical evidence remains insufficient to fully support its long-term efficacy. Design: Lingual plate, C clasps engaging at 0.5 mm undercut

Table 2.3
Clinical Studies Related to PEEK Materials in RPD

Author	Objectives	Subjects	Author' remark
Periodontal parameter			
Zhai et al., 2025	To compare the clinical performance (mobility, gingival index and patient satisfaction) of Bio-HPP and Vitallium frameworks in Kennedy Class I and II free-end RPDs	80 patients (40 Bio-HPP, 40 Vitallium) Randomized clinical trial (Baseline and 1 year)	<u>Clinical reported outcome</u> Bio-HPP and Vitallium frameworks showed no significant difference in gingival index or abutment loosening after one year, indicating similar periodontal outcomes despite different material properties. <u>Patient reported outcome</u> In term of patient satisfaction (using VAS), Bio-HPP better in aesthetics and comfort ($P < 0.05$) and Vitallium better in stability ($P < 0.05$), but no significant difference in pronunciation and clarity
Ali et al., 2020	To investigate differences in the performance of PEEK vs CoCr frameworks for RPDs in terms of OHRQoL, patient preference, periodontal indices, and denture satisfaction in one year period	25 participants were received CoCr and PEEK denture (1-year follow up =19 patients)	<u>Clinical reported outcome</u> Similar periodontal outcomes as CoCr denture frameworks. <u>Patient reported outcome</u> PEEK denture frameworks have similar effect on OHRQoL, patient satisfaction as CoCr denture frameworks (OHIP-14)
Fit and accuracy			
Ge et al., 2025	To compare fit, mastication efficiency, clinical efficacy, and satisfaction between completely digital and semi digital workflows for PEEK RPDs.	20 participants Kennedy Class I–III Each received two PEEK RPDs	<u>Clinical reported outcome</u> Both workflows produced good fit, but completely digital PEEK RPDs improved comfort and fit at distal extensions and rests. <u>Patient reported outcome</u> Using non-validated survey, mastication efficiency and overall satisfaction was similar

Author	Objectives	Subjects	Author' remark
Fit and accuracy			
Yoon et al., 2024	To explore clinical application of one-piece PEEK RPDs made with a novel digital workflow, evaluating weight, fit in vivo, and patient satisfaction compared with conventional RPDs.	15 participants (8 maxillary: 7 mandibular) Kennedy Class I–III Each received two RPDs: PEEK (test) and CoCr (control).	<u>Clinical reported outcome</u> One-piece PEEK RPDs from the novel digital workflow were lighter and had acceptable in vivo fit <u>Patient reported outcome</u> using VAS; had aesthetic advantage for clasps but comfort and mastication similar to conventional.
Maraka & Alaa'a Salloum, 2021	To evaluate the fit accuracy of the RPDs frameworks fabricated by digital and conventional method.	Five patients (conventional CoCr) Five patients (milled PEEK RPDs)	<u>Clinical reported outcome</u> Accuracy Cr-Co frameworks fabricated using conventional casting were less accurate as compared to PEEK CAD/CAM.
Microbiology assessment			
Mansour et al., 2020	To compare the adhesion of Candida albicans to the fitting surface and mucosa underneath of Bre-Flex versus PEEK RPD.	18 patients (9 Bre Flex: 9 PEEK)	<u>Clinical reported outcome</u> Bre-Flex group shows higher number of Candida colonies in comparison to the number of colonies in PEEK group
Medappa, 2018	To assess the influence of surface roughness on bacterial adhesion in PEEK	10 participants (5 control: 5 PEEK)	<u>Clinical reported outcome</u> Increase in surface irregularities and the presence of microbial colonies, predominantly gram-positive cocci. However, the evaluation timeframe is restricted to a brief 24-hour period, posing a significant limitation for comprehensive assessment.

Author	Objectives	Subjects	Author' remark
Patient related studies outcome only			
Hegazi et al., 2025	To compare the OHRQoL and patient satisfaction results between PEEK and CoCr RPD frameworks	30 patients (15 PEEK: 15 CoCr) Kennedy Class I	<u>Patient reported outcome</u> Both indirect CAD-CAM PEEK and CoCr RPDs significantly improved OHRQoL and patient satisfaction beyond the mnimally clinically important difference, supporting their acceptability from the patient's perspective (using OHIP-14, SLRD-Q) <u>PEEK Design specification detail</u> Undercut 0.50 mm Thickness 2.4 mm (increased to 2.8 mm to allow for finishing)
Mohamed & Rasha, 2019	To investigate patient satisfaction metal versus PEEK RPD framework in three-month period	10 participants (5 PEEK: 5 CoCr)	<u>Patient reported outcome</u> Digitally milled PEEK frameworks increase patient satisfaction as compared to conventionally manufactured metal RPD frameworks.
Other clinical studies			
Oliveira et al., 2025	To compare masticatory performance (MP), maximum bite force (MBF), and patient satisfaction between CoCr and injected PEEK RPD frameworks.	12 participants Randomized crossover: each used both CoCr and PEEK RPDs for 2 months each, with 1-week washout	<u>Clinical reported outcome</u> Majority preferred CoCr as it provided better masticatory performance <u>Patient reported outcome</u> Using VAS, higher satisfaction in stability and chewing than PEEK; MBF similar <u>PEEK Design specification details</u> Undercut 0.25 mm Major connectors 5 mm, saddles 1.7 mm, rests 1.2 mm thickness.

Author	Objectives	Subjects	Author' remark
			In clasp region, thicknesses (measured from the terminus of the clasp's retentive arm to its connection with the saddle) ranged from 1.0 to 3.4 mm. Minor connectors had thicknesses (measured from the rests to the junction with the major connector) ranged from 1.4–4 mm
Lo Russo et al., 2022	To provide 1-year clinical case-control study on edentulous residual ridge dimensional changes for patients wearing PEEK RPD and a control group of untreated patients.	6 untreated patients (Control) 10 received PEEK RPD	<u>Clinical reported outcome</u> No short-term differences in edentulous residual ridge height and overall dimensions between patients wearing PEEK RPD, fabricated with a digital workflow, and controls without an RPD
Eldien, 2020	To evaluate the force of retention immediately, 3 months and six months after denture insertion.	Five patients (milled PEEK RPDs) Five patients (3D printing CoCr)	<u>Clinical reported outcome</u> The retention forces in CoCr RPDs were higher than PEEK RPDs) engaging the same undercuts (0.25 mm).

2.10 Evidence from Previous in Vitro Studies

2.10.1 PEEK clasp/ Direct Retainer in RPD Design

Table 2.4 summarized characteristics of in vitro studies related to RPDs clasp materials manufactured from PEEK material. The clasp design of PEEK RPDs, as examined in various in vitro studies, primarily focuses on achieving optimal retention and flexibility due to PEEK's unique material properties with most comparison with CoCr with one study used graphene-based polymer (GBP) as a comparison with majority of the study use the pull-off test method. The pull-off test, also known as the insertion/removal test, is a method used in in vitro studies to evaluate retention force. This test employs a masticatory simulator, where specimens are removed from abrasion-resistant models to permit vertical movement of the clasp. This movement simulates the insertion and removal of a RPD while ensuring consistent measurement conditions throughout the test (Tannous et al., 2012).

Unlike metal frameworks, PEEK's flexibility allows it to engage deeper undercuts without causing excessive force on the abutment teeth, thereby enhancing patient comfort. Studies have evaluated various undercut depths for PEEK clasps, most commonly 0.25 mm, 0.50 mm, and 0.75 mm (Bradfield et al., 2025; Lee et al., 2024; Muhsin et al., 2018). Muhsin et al. reported that PEEK clasps engaging a 0.75 mm undercut exhibited the highest initial retentive forces, demonstrating that PEEK's flexibility enables greater retention even at larger undercuts without compromising stability, cause irritation to abutment teeth or increasing fracture risk (Zheng et al., 2023; Muhsin et al., 2018). However, a more recent in vitro study by Lee et al. suggests that increasing clasp cross-sectional dimensions may be more critical than increasing undercut depth for achieving adequate retention (Lee et al., 2024). This study is the only in vitro study to report detailed, standardized design specifications for PEEK clasps, systematically varying both clasp geometry and undercut depth.

In contrast, most previous studies evaluated PEEK clasps using fixed clasp dimensions, typically 1.0 mm or 1.5 mm in thickness, with limited emphasis on systematic variation in width and height (Güleryüz et al., 2021; Tannous et al., 2012). A range of clasp configurations, including Akers and Bonwill designs, has been examined across studies, with results consistently indicating that both clasp design and thickness significantly influence retentive force and long-term durability under

simulated masticatory loading and repeated insertion and removal cycles (Gentz et al., 2022; Hussein, 2022; Micovic et al., 2021). Lee et al. evaluated two clasp designs, which are a tapered clasp with variable thickness and a uniform 1.5 mm thickness and increased width, tested at 0.50 mm and 0.75 mm undercuts over 15,000 insertion and removal cycles simulating long-term clinical use. The findings showed that increased cross-sectional dimensions, particularly in the uniform thickness design, exerted a greater influence on retentive force than undercut depth, with PEEK clasps demonstrating higher retention stability and reduced permanent deformation (Lee et al., 2024).

However, it is also important to note that the effect of the manufacturing method remains inconclusive. Some studies reported comparable retentive performance between milled and pressed PEEK clasps, whereas others demonstrated superior resistance of milled PEEK following thermocycling or water storage, suggesting improved stability under thermal and moisture-related ageing (Soares et al., 2025). Furthermore, substantial variation exists in ageing simulation protocols, with mechanical cycling ranging from a few thousand to over 20 000 cycles across studies (Mayinger et al., 2021; Muhsin et al., 2018), limiting direct comparison and contributing to inconsistent conclusions regarding the long-term retention and durability of PEEK clasps.

Despite methodological variation across studies, *in vitro* evidence consistently demonstrates the favourable fatigue resistance and long-term stability of PEEK clasps, even under extensive cyclic loading designed to simulate years of clinical use. While increasing clasp thickness generally enhances retentive performance, this approach may compromise aesthetics due to increased visibility, potentially affecting patient satisfaction in situations where appearance is a concern. Consequently, future PEEK clasp designs should aim to balance mechanical performance with aesthetic considerations by optimizing retention while minimizing visible bulk. In conclusion, current *in vitro* evidence supports the promising potential of PEEK for clasp applications in RPD; however, the establishment of standardized design parameters remains essential to ensure predictable performance and broader clinical settings.

Table 2.4

In Vitro Studies Related to RPDs Clasp/Direct Retainer Manufactured by PEEK Material

Author, Year	Study's assessment	Sample/ Material tested	Materials and methods	Author remark
Bradfield et al., 2025	Flexibility and fracture point	n=40 (10 per group) PEEK CoCr (cast, milled printing)	Design: Aker clasp (7 mm long, 2 mm thick and half-round in cross-section) with different undercut 0.25 mm, 0.50 mm and 0.75 mm	Laser-printed CoCr clasps exhibited the highest fracture point especially in deeper undercuts. 0.75 mm yielded the highest retention for PEKK, but the force was still far below the clinical requirement for a functional denture clasp. Milled PEKK clasps fractured at a significantly lower force (45.10 N), rendering them unsuitable for clinical use as retentive clasps.
Lee et al., 2024	Retention and deformation	PEEK	Design: Double Akers clasps with different thicknesses & undercuts (0.50 mm & 0.75 mm). Simulated 15,000 insertion/removal cycles.	PEKK had higher flexural modulus than PEEK, reducing clasp deformation. Both materials maintained sufficient retention after 10 years of simulated use. PEEK and PEKK are viable alternatives to metal clasps, but PEKK is less prone to deformation.
Hussein, 2022	Mechanical performance	n= 32 (16 per group) Did not mention the undercut used GBP PEEK	Design: Aker clasp Simulated 10,000 insertion/removal cycles with 10,000 thermocycle process to stimulate effect of oral environment aging 3D deviation of the clasps' arms	Gradual decrease in the retentive force for both materials, with retention force is higher in PEEK compare to GBP. GBP showed higher deformation than PEEK for clasp arms' deformation Maximum principal stress found at the retentive terminal and guiding plane in the GBP clasp than in the PEEK clasp.

Author, Year	Study's assessment	Sample/ Material tested	Materials and methods	Author remark
Güteryüz et al., 2021	Retentive force and dimensional change	n= 32 (16 per group) PEEK (at undercuts of 0.25 mm or 0.50 mm) and different thickness (1.0 mm and 1.5 mm)	Design: Aker clasp Simulated 7200 insertion/removal cycles (thermo-mechanical fatigue) Dimensional changes: evaluated using microCT initial and final image Surface of clasp evaluated using scanning electron microscope	Thermo-mechanical aging decreases the retentive force in PEEK clasps. Increasing the thickness and UC of clasps, decreases the amount of dimensional change.
Mayinger et al., 2021	Retention force	n=60 (15 per group) Did not mention the undercut used CoCr (Control) DentoKepp (PEEKmilled1) BioHPP Blank (PEEKmilled2) BioHPP Granulat (PEEK pressed)	Design: Bonwill clasps Pull-off test (retention force) was examined at different aging levels at 30 days (10,000 thermal cycles) and 60 days (20,000 thermal cycles) *20,000 thermal cycles-simulate a clinical period of 2 years	.PEEKmilled2 presented superior results than PEEKpressed. Artificial aging led to a significant decline in retention force for all PEEK-based materials while CoCr recorded higher values after artificial aging All materials exhibited sufficient retention to recommend usage under clinical conditions
Micovic et al., 2021	Retention force	n=60 (15 per group) Did not mention the undercut used CoCr (Control) DentoKepp(PEEKmilled1) BioHPP Blank (PEEKmilled2) BioHPP Granulat (PEEK pressed)	Design: Bonwill clasps Retention force was examined using the universal testing machine at initial, 90 days and 180 days of aging time.	Control group showed significantly higher retention force values than PEEK. The manufacturing process of PEEK (milled vs pressed) did not influence the retention force. While the control group was susceptible to artificial aging, PEEK materials presented constant results.

Author, Year	Study's assessment	Sample/ Material tested	Materials and methods	Author remark
Muhsin et al., 2019	Retentive force	n=90 (10 per group with different undercut 0.25 mm, 0.50 mm, 0.75 mm) CoCr Thermo-pressed PEEK Optima Machined PEEK-Juvora™	Design: “novel clasp design” ie short arm for aesthetic purposes Simulated 6600 insertion/removal cycles.	PEEK clasps exhibited no tendency to fracture at any undercut depths over the tested period The highest initial retentive force of 45 N was observed with the PEEK-Juvora™ clasps of 0.75 mm undercut depth, followed by the PEEK-Optima® at 0.75 mm (35 N)
Arnold et al., 2018	Fit	Complete palatal strap Case: Class 4 Mod 2	Evaluate fit of the retentive clasps (12 clasps; 6 canines, 6 molars) horizontal and vertical measurement. Technique: IRP, DRP,IM, DM and LWT (Control)	Direct CAD/CAM milling process showed a significantly better fit than LWT RP exhibited the highest discrepancies All RPDs fabricated by using techniques that included casting procedures revealed higher horizontal than vertical discrepancies because of greater distortion
Tannous et al., 2012	Retentive force	n=112 (16 per group with different undercut (0.25 mm, 0.50 mm) and different thickness (1.0-1.5 mm except CoCr with only 1.0 mm thickness)) CoCr (Control) PEEK, PEKK,POM	a) Used “straight semicircular clasp patterns” resembling aker clasp design b) insertion/removal test simulating 10 years use.	Thermoplastic resin clasps-maintained retention over 15,000 joining and separating cycles with significantly lower retention than CoCr clasp. However, it is sufficient for clinical use

LWT=lost-wax technique; IRP= Indirect rapid prototyping; wax inject printing combined with LWT); DRP= Direct rapid prototyping; IM= Indirect milling (wax milling with LWT), DM= Direct resin milling, POM= Polyoxymethylene

2.10.2 Occlusal Rest Design for RPD in PEEK

Rests are essential components of RPD frameworks, providing vertical support, distributing occlusal forces to the abutment teeth, and stabilizing the prosthesis (Rice et al., 2011; Phoenix et al., 2003). Comparing CoCr and PEEK as rest materials highlights significant differences in their distinct physical and mechanical properties. CoCr alloys possess a modulus of elasticity of approximately 200 GPa, which is substantially higher than that of PEEK, allowing for efficient force distribution with minimal flexure (Najeeb et al., 2016).

Classic prosthodontic literature recommends metal occlusal rests with a spoon-shaped depression, a buccolingual width of at least 2.0 mm, a mesiodistal length covering one-third of the crown dimension, and a minimum thickness of 1.0 mm. These specifications help prevent material failure and ensure effective load transfer. Inadequate thickness or improper angulation can result in fracture or deformation, compromising RPD stability and indirect retention (Carr & Brown, 2010; Phoenix et al., 2003; Sato et al., 2003). However, whether these design principles apply to PEEK remains uncertain because of its lower stiffness and distinct mechanical behaviour.

To date, no in vitro studies have specifically evaluated occlusal rest designs for PEEK frameworks, limiting available evidence for optimizing their dimensions and morphology (Table 2.5). Two studies have assessed the accuracy of PEEK dentures (including rests), albeit with differing methodologies. One study compared direct milling and indirect additive manufacturing using a thermopress process, finding that the direct technique achieved slightly higher accuracy (Negm et al., 2019). Another study compared PEEK rests fabricated via CAD/CAM milling with CoCr rests produced through traditional casting, concluding that PEEK frameworks demonstrated superior accuracy (Ye et al., 2018). Despite differences in methodology, both studies highlighted the benefits of direct milling for achieving a precise fit in PEEK frameworks, particularly in the rest area. However, the lack of standardized evaluation methods emphasises the need for more uniform research approaches.

The scarcity of in vitro studies addressing PEEK occlusal rests causes several critical questions to remain unanswered. Currently, no standardized design guidelines exist for PEEK occlusal rests, and the applicability of conventional metal-rest parameters remains unverified. Fractures often occur at the transitional area between the rest and minor connector, especially across the marginal ridge of the abutment tooth

(Carr & Brown, 2010). Future in vitro research is essential to bridge these gaps, focusing on evaluating different occlusal rest configurations with different design parameters such as different widths, thickness, and curvature to enhance durability and minimize stress concentration. Such investigations would yield robust data to validate PEEK as a viable material for occlusal rests and to support the development of clinically optimized design guidelines.

Table 2.5
Studies Evaluating Rest in PEEK RPDs

Author, Year	Study's assessment	Objective	Materials/Methods	Result (Mean/ SD)	Author remark
Negm et al., 2019	Accuracy	To compare the accuracy of fit and trueness PEEK fabricated by direct and indirect computer-aided design/computer-aided manufacturing (CAD/CAM) techniques.	N=20 PEEK only (10 direct CAD/CAM, 10 indirect additive manufacturing) Accuracy of fit was assessed using a color map was constructed using metrology software (Geomagic Control-X; 3D Systems	PEEK-Direct (mm) Rest: 0.07 ± 0.09 PEEK-Indirect (mm) Rest: 0.05 ± 0.07	No comparison with CoCr RPD, focus on different manufacturing technique (ie direct milling verses indirect rapid prototyping combined with thermopress technique).
Ye et al., 2018	Accuracy	To evaluate fit of PEEK vs CoCr RPD in different area of RPD	N=30 15 PEEK, 15 CoCr using silicone and Geomagic Qualify software	PEEK (mm) Rest: 86.2 ± 22.6 CoCr (mm) Rest: 133.9 ± 49.7	PEEK was constructed using milling technique while CoCr was constructed using using traditional technique Accuracy in rest were better in between milled versus traditional fabrication technique.

2.10.3 PEEK as Major Connectors

The design of RPD major connectors is guided by individual clinical requirements and the material used. Differences between PEEK and CoCr frameworks arise primarily from their distinct material properties. CoCr is a rigid and durable material that provides excellent support and stability, but its high density and thermal conductivity may result in heavier frameworks and patient discomfort (Akl & Stendahl, 2022). Consequently, CoCr major connector designs emphasize rigidity, adequate thickness, minimal interference with oral structures, and effective distribution of functional forces. Common designs such as the maxillary palatal plate and mandibular lingual bar aim to maximize stability while avoiding tissue impingement, as insufficient rigidity can lead to uneven load transfer and compromise prosthesis longevity (Carr & Brown, 2010).

In contrast, PEEK major connector designs are less standardized and are often guided by manufacturer recommendations due to the absence of well-established clinical guidelines. These designs reflect PEEK's lower elastic modulus, flexibility, and favourable biocompatibility. In the mandible, anatomical limitations restrict connector options mainly to lingual bars or plates, where rigidity is strongly influenced by cross-sectional geometry. A half pear-shaped cross-section, for example, can enhance stiffness in situations with limited vertical space. While some flexibility may help absorb masticatory forces, excessive flexibility may increase torque and risk of clasp deformation, highlighting the need for careful dimensional optimization when using PEEK (Ben-Ur et al., 1999).

While CoCr frameworks adhere to standardized design principles, PEEK designs are often influenced by manufacturer-specific recommendations due to the lack of established clinical guidelines for this relatively new material. These recommendations influence PEEK's unique properties, including its flexibility and biocompatibility. In the mandible, anatomical constraints limit major connector designs to the lingual bar or lingual plate. The rigidity of mandibular connectors depends significantly on their cross-sectional shape. For example, a half pear-shaped cross-section enhances stiffness and stability, particularly when the space between the gingival margin and the floor of the mouth is limited. Flexibility in the mandibular major connector is necessary to absorb vertical masticatory forces, but excessive flexibility can lead to torque and clasp deformation (Ben-Ur et al., 1999).

Most in vitro studies on PEEK major connectors focus on mechanical strength and accuracy, both of which are crucial for functional efficiency and patient comfort. However, evaluation of accuracy should not be limited to overall framework fit but should also include detailed analysis of connector dimensions, particularly width and height, as well as thickness uniformity, and cross-sectional geometry. Clinically, RPD allows a relatively wide tolerance for accuracy, with a gap of 0 to 50 μm between the framework and cast considered a close fit (Soltanzadeh et al., 2019), and gaps up to 426 μm are regarded as clinically acceptable (Curinga et al., 2023b). Among the four available studies assessing PEEK major connector designs, three focused on maxillary connectors, while only one investigated a mandibular design, specifically a lingual bar (Table 2.6). This imbalance highlights a significant gap in the literature, particularly regarding mandibular PEEK major connectors, where systematic evaluation of connector dimensions, including width, height, thickness distribution, and their influence on fit, rigidity, and clinical performance, remains largely unexplored.

Additionally, beyond mechanical performance and accuracy, future studies should examine microbial adhesion and biocompatibility, with a focus on bacterial colonization and the soft-tissue response to PEEK major connectors. Research on thermal and hygroscopic behaviour is also essential to assess PEEK's dimensional stability under oral conditions. Furthermore, alternative design strategies, such as reinforced PEEK or hybrid PEEK-metal frameworks, should be investigated to enhance rigidity without increasing thickness. These studies will contribute to the development of clinical guidelines to ensure optimal strength, accuracy, and biocompatibility of PEEK major connectors.

Table 2.6

In vitro Study Focusses on PEEK Major Connector

Author, Year	Study's assessment	Major connector design	Method	Author remark
Elsayed el al., 2022	Mechanical properties	Single palatal strap Case: Kennedy Class III A-P dimension: Both designs were not <8 mm to ensure sufficient rigidity Different design thickness - CoCr alloy straps were 0.7 mm - PEEK strap was 1.4 mm.	Specimens were created using CAD/CAM technology and fabricated via thermal injection molding (PEEK) or centrifugal casting (CoCr). Evaluated fracture resistance, field emission microscopy (FEM) and energy dispersive spectroscopy (EDAX) to analyse microstructure and elemental composition and atomic absorption spectroscopy (AAS) to analyse storage water for leaching elements.	Fracture Resistance: CoCr specimens demonstrated significantly higher mean maximum compression load (MCL) values than PEEK specimens in both stored and non-stored conditions. PEEK straps often showed deformation rather than fracture. Microstructure: FEM revealed ceramic filler agglomerations in non-stored PEEK specimens, which were largely absent in stored specimens, indicating leaching. Biodegradation: AAS detected aluminum leaching from PEEK composite storage water, raising biocompatibility concerns.
Guo et al., 2022	Mechanical properties and fit	Single palatal strap with 3 different designs with no details design specification - Design 1: One-piece PEEK RPD printed by FDM - Design 2: FDM-printed	For mechanical evaluation, PEEK samples were prepared using fused deposition modeling (FDM), milling, and injection molding to evaluate and compare their mechanical properties where tensile, flexural, and compressive properties were evaluated using standardized testing protocols.	Mechanical Properties: Tensile strength showed no significant differences across the manufacturing methods. Flexural and compressive strengths were highest for milled PEEK, followed by injection molding and FDM. FDM-printed samples exhibited internal pores and weaker interlayer bonding, reducing flexural strength.

Author, Year	Study's assessment	Major connector design	Method	Author remark
		• PEEK framework and porcelain teeth • Design 3: FDM-printed PEEK framework, base plate and artificial tooth *Design 1 was used for evaluation for fitting	Scanning electron microscopy (SEM) was used to analyse the microstructure of fractured surfaces For FEA, 3 RPD designs were created, and the stress, strain, and displacement of the frameworks, cortical bone, and mucosa were analysed under a vertical load of 120 N. Five FDM-printed PEEK RPDs were evaluated using silicone rubber impressions and Geomagic Qualify software to analyse deviations between the frameworks and tissue models.	FEA FEA revealed that PEEK frameworks had lower stress on abutments and cortical bone compared to CoCr and titanium but higher stress on mucosa. PEEK showed no pathological bone absorption under loading conditions. Fit The average deviation between the FDM-printed RPDs and tissue models was 0.277 ± 0.079 mm, within clinically acceptable limits.
Negm et al., 2019	Accuracy and trueness	A-P palatal strap Case: Kennedy Class 1 Design: Anteroposterior palatal strap major connector, RPI clasps on first premolars, and canine rests	Frameworks were fabricated using: Direct Technique: Milling PEEK frameworks from BioHPP blanks. Indirect Technique: 3D-printed resin patterns followed by thermopressing PEEK using the lost-wax method. Accuracy of fit: Frameworks were scanned and compared to the reference cast using color mapping at 25 standardized points. Trueness: Each framework's STL file was superimposed over the original digital design to measure deviations.	Use two CAD/CAM techniques with no comparison with CoCr Fit The direct technique showed better overall fit (0.11 ± 0.03 mm) compared to the indirect technique (-0.09 ± 0.05 mm). The indirect technique displayed more pressure areas in anterior and posterior strap regions, while the direct technique had a more uniform fit. Significant differences in accuracy were noted in the guiding planes and strap areas, favouring the direct technique. Trueness

Author, Year	Study's assessment	Major connector design	Method	Author remark
				The direct technique had significantly better trueness ($17.36 \pm 4.32 \mu\text{m}$) compared to the indirect technique ($71.68 \pm 17.54 \mu\text{m}$). The milling process maintained higher precision and better surface finish, preserving stippling details.
Ye et al., 2018	To evaluate fit of PEEK vs CoCr RPD in different area of RPD (rest, major connector, denture base, entirely)	Lingual palatal bar Case: Kennedy Class 2 Div 1	N=15 RPDs were designed using dental CAD and reverse engineering software and milling	Fit One-piece PEEK RPDs can be successfully designed and fabricated using CAD/CAM methods and the fit was superior to that of traditional cast framework RPDs. Apart from MC, it also evaluated accuracy or entire denture, rest and denture best.

2.10.4 Other in Vitro Studies in Related to PEEK Denture-based Material

Beyond mechanical strength and fit accuracy, several in vitro studies have examined other clinically relevant aspects of PEEK, including colour stability, surface treatment, bonding performance, and cleaning protocols, to optimise its use in removable partial dentures. Colour stability is particularly important, as discoloration compromises aesthetics and patient satisfaction and is often considered an aesthetic failure. Staining may result from extrinsic factors such as food, beverages, and tobacco, as well as intrinsic material properties, including chemical composition and surface characteristics (Ayaz & Ustun, 2020; Sepúlveda-Navarro et al., 2011). Surface roughness and surface energy further influence colour stability, as rougher surfaces facilitate greater pigment adhesion (Heimer et al., 2017).

Three in vitro studies have specifically investigated staining effects on PEEK denture base materials using different experimental approaches (Table 2.7). Papathanasiou et al. (2022) compared PEEK with polyamide and acetal resin and reported that PEEK exhibited the least colour change, although it showed greater gloss alteration, with coffee identified as the most aggressive staining agent (Papathanasiou et al., 2022). Porojan et al. (2021) focused solely on PEEK and demonstrated that artificial ageing adversely affected colour stability and surface roughness, while glazing improved surface regularity and optical properties (Porojan et al., 2021). Polychronakis et al. (2020) further showed that PEEK discoloured less than polyoxymethylene under combined staining and cleansing protocols, highlighting the potential protective role of cleaning agents (Polychronakis et al., 2020). A more recent study by Erdağ et al. (2023) reported minimal colour change and surface degradation following chemical and mechanical cleaning; however, the use of a single PEEK type and staining medium limits clinical extrapolation. Although these studies indicate that PEEK demonstrates superior colour stability compared with some denture base polymers, it remains susceptible to staining, particularly from coffee, and that glazing and appropriate cleaning protocols may mitigate these effects (Erdağ et al., 2023).

Another important limitation of PEEK is its inherent hydrophobicity, which compromises adhesive bonding to denture base resins and artificial teeth. Surface modification techniques such as air abrasion, acid etching, and tribochemical silica coating have therefore been investigated to enhance surface wettability and micromechanical retention. Previous studies had demonstrated that surface treatment

significantly influences bond strength, with air abrasion and tribochemical silica coating showing favourable results, while acid etching improved bonding to PEEK but reduced bond strength to CoCr (Jassim & Jaber, 2019; Kurahashi et al., 2019) (Table 2.7). Variations in resin type and surface treatment parameters likely contributed to differences in outcomes. Nevertheless, existing evidence supports the importance of personalised surface modification strategies for improving PEEK bonding performance, although further studies using standardized testing protocols are required to establish reliable clinical guidelines.

Table 2.7

Other in Vitro Studies Related to PEEK Denture Base Material

Author, Year	Study's assessment	Material tested	Conclusion
Effect of staining in PEEK denture base material			
Papathanasiou et al., 2022	To assess the effect of commonly used solutions (coffee, red wine, coca cola distilled water) on colour stability, gloss, and surface roughness of RPDs prostheses polymers.	PEEK Polyamide Acetal resin PMMA	PEEK presented the lowest colour change but showed highest alteration of gloss Polyamide had the highest colour changes. Coffee caused the highest colour and gloss changes among different immersing solutions. Material surface roughness was not influenced by immersing solutions.
Porojan et al., 2021	To determine the influence of different ageing and staining protocols on optical properties, color changes, and surface roughness of PEEK	PEEK (BioHPP)	Glazing of PEEK has a positive impact on surface irregularity and opalescence, regardless of the artificial ageing or staining protocols. Artificial ageing damages the colour stability and roughness of PEEK decrease the translucency and opalescence of glazed surfaces.
Polychronakis et al., 2020	To investigate the long-term effect of staining and/or cleansing solutions (water, wine, coffee, cleanser and combo bath) on the colour stability of two RPDs polymers. <i>*Combo bath:wine-water-coffee-water-cleanser-water</i>	PEEK polyoxymethylene (POM)	POM discoloured more than PEEK in coffee, and combo baths but not in cleanser. Discoloration was smaller in combo bath (where a cleanser was also used) indicating the effectiveness of a cleanser to prevent long term discoloration of both materials.
Effect of PEEK on different surface treatment and cleaning methods			
Erdağ et al., 2023	To evaluate the effect of different denture cleaning methods (chemical and mechanical) on the surface roughness and color stability of polyether ether ketone (PEEK) used in dental applications.	PEEK	It evaluated 3 chemical cleaning groups: 5% sodium hypochlorite (NaOCl), alkaline peroxide tablet (Corega) and 0.12% chlorhexidine gluconate (CHX) and 3 mechanical cleaning groups: Toothbrush + toothpaste, toothbrush + soap and toothbrush + denture cleansing gel PEEK maintained surface roughness below the biofilm retention threshold and exhibited clinically acceptable color changes regardless of cleaning method.

Author, Year	Study's assessment	Material tested	Conclusion
			Both chemical and mechanical denture cleaning procedures can be safely used for PEEK without significant adverse effects on surface roughness or color stability.
Jassim & Jaber, 2019	To evaluate the bonding efficiency between heat-activated denture base resin to CoCr and PEEK polymer focused on the different surface treatments (acid etch and air abrasive)	acrylic- CoCr acrylic- PEEK	It evaluated 3 types of surface treatments: No treatment Al₂O₃ sandblasting and 98% acid sulfuric Evaluations were done in five sections: SEM, X-ray diffraction analysis, fourier transforms infrared spectroscopy (FTIR), Bond Strength Test and Failure Analysis Air abrasive surface treatment significantly improved bond strength for both CoCr and PEEK. Acid etch surface with CoCr alloy show a significant decrease in bond strength to acrylic resin, while for PEEK polymer demonstrate significantly superior bond strength the acrylic resin Heat acrylic resin showed statistically higher bond strength with PEEK polymer than CoCr alloy
Kurahashi et al., 2019	To investigate the effect of PEEK surface treatments on the shear bond strength to acrylic resin	CoCr and PEEK with two types of resin (Unifast and Palapress Vario).	For PEEK, 5 surface treatment were evaluated. No treatment (Control), ceramic primer application, Al₂O₃ sandblasting, tribochemical silica airborne-particle abrasion (Rocatec) and Rocatec with ceramic primer application While surface treatment for CoCr is metal primer Rocatec treatment, combined with ceramic primer, showed the highest bond strength of PEEK to acrylic resin (both Unifast II and Palapress Vario)

2.11 Conclusion from Case Reports, Clinical, and in Vitro Studies on PEEK RPDs

Evidence from case reports, clinical studies, and in vitro studies collectively supports PEEK as a viable alternative to CoCr for RPD frameworks, offering advantages in weight reduction, metal-free composition, improved aesthetics, and potential for patient comfort. Figure 2.12 summarizes all the studies related to PEEK RPD. Overall, case reports highlight satisfactory fit, acceptable retention, and high patient acceptance, although many lack detailed design specifications, limiting reproducibility. Clinical studies demonstrate that PEEK can achieve functional and periodontal outcomes comparable to those of metal frameworks, with some reports of improved patient satisfaction; however, results remain mixed and may be influenced by denture design and operator factors rather than material alone. In vitro investigations confirm PEEK's acceptable accuracy, adequate flexural strength and adaptability to deeper undercuts, but also reveal lower modulus of elasticity and fatigue resistance compared with CoCr, necessitating increased component thickness or bulk to maintain durability. Despite promising short-term outcomes, the absence of standardized design guidelines particularly for the commonly used lingual plate connectors highlight the need for long-term clinical studies to optimize PEEK's application in RPDs.

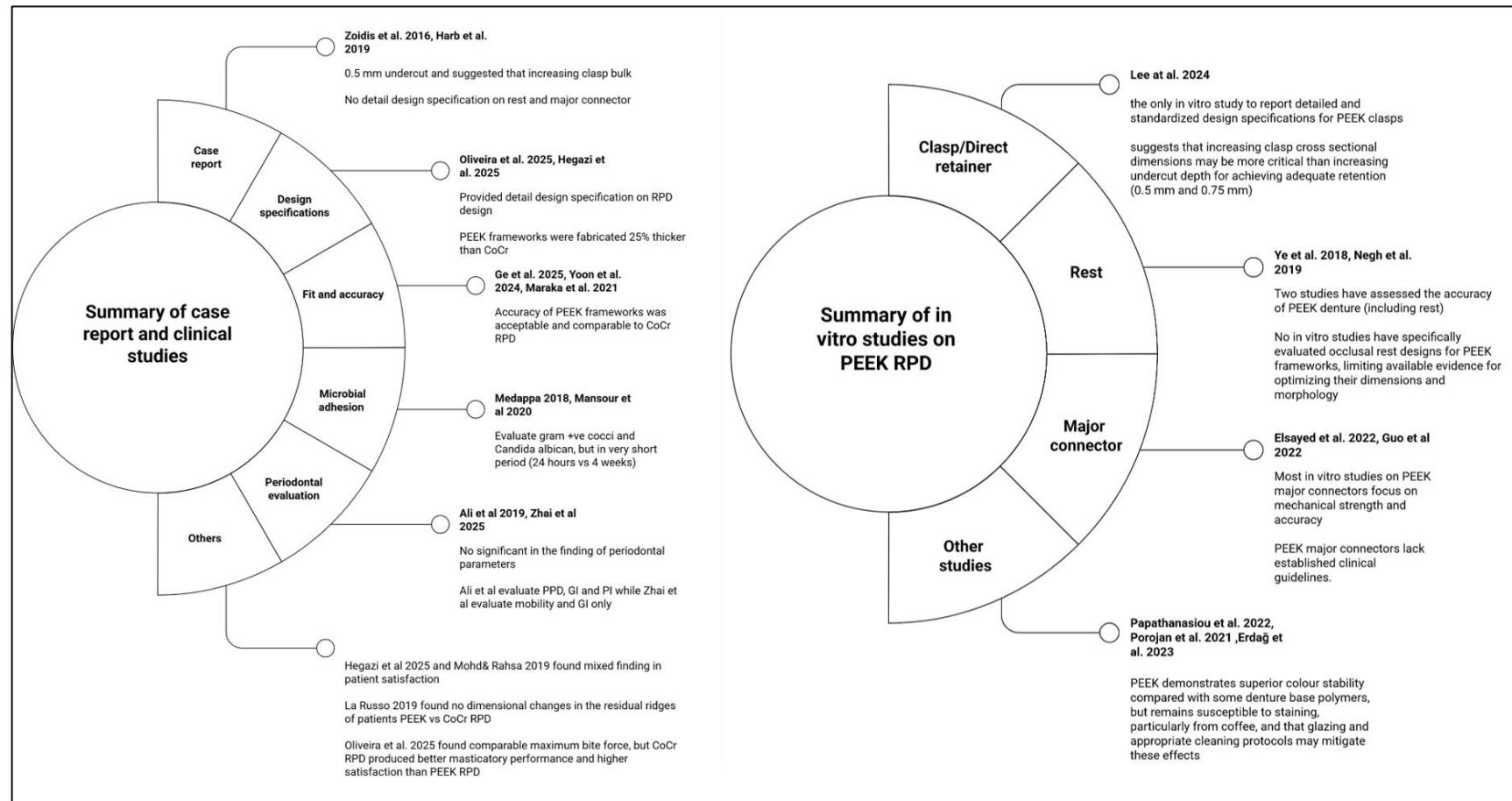


Figure 2.12 Summary of Case Reports, Clinical Studies and in Vitro Studies on PEEK in Removable Partial Dentures

2.12 Application of Finite Element Analysis in RPDs

Finite element analysis (FEA) has become an essential computational tool in dentistry, enabling researchers and clinicians to model and analyse the biomechanical behaviour of prosthetic devices, including RPD (Shahmiri & Das, 2017; Ko et al., 2012). By simulating the complex mechanical interactions between prosthetic materials and biological structures, FEA aids in optimizing RPD designs, particularly in scenarios where experimental testing is challenging or impractical. This method employs computational procedures to determine stress distribution within a structure, providing a model-based solution to analyse the effects of external forces, pressure, or thermal changes (Shivakumar et al., 2021; Wakabayashi et al., 2008). Moreover, FEA provides a method to investigate the mechanical properties of biomaterials and oral mucosa, which help saving time and resources (Ko et al., 2012; Trivedi, 2014).

The application of FEA in RPD design and analysis involves several key steps. The process begins with the creation of a detailed virtual model that represents both the anatomical structures including the abutment teeth, PDL, supporting mucosa and bone as well as the RPD framework. This model incorporates all essential components, such as the major and minor connectors, clasps, rests, and artificial teeth, allowing for a realistic simulation of clinical conditions (Chen et al., 2019; Shahmiri et al., 2014). The accuracy of FEA results heavily depends on the precise representation of geometry and material properties. Each component's material properties, including Young's modulus and Poisson's ratio, are assigned based on experimental data or manufacturer specifications (Chen et al., 2019; Shahmiri et al., 2014).

Following the definition of material properties, boundary conditions are applied to mimic clinical scenarios. These conditions include applied loads simulating occlusal forces during mastication and constraints representing the support provided by surrounding tissues. The model is then discretized into a mesh of finite elements; a crucial step as the accuracy of results depends on the element size and type. After defining the material properties and boundary conditions, the FEA software solves a system of equations to determine stress, strain, and displacement within each element. (Shivakumar et al., 2021; Mohammed & Desai, 2014). This process provides a detailed visualization of mechanical behaviour under functional loading conditions.

A thorough analysis of the results allows for the identification of stress concentrations, potential failure points, and areas of excessive deformation (Lyu et al.,

2023; Chen et al., 2019). As FEA able to provide detailed visualization of stress distribution across key parameters and predict how stresses are distributed within the framework and supporting structures, it essentially helps to refine RPD design (Guo et al., 2022; Chen et al., 2019; Shahmiri & Das, 2017; Muraki et al., 2004). Traditionally, clinical failures such as abutment tooth fractures, periodontal breakdown, and prosthetic fractures were linked to insufficient understanding of the underlying biomechanical forces. FEA bridges this gap by simulating functional loading on virtual models, offering valuable insight into the behaviour of various materials and designs under masticatory forces (Chen et al., 2019; Shahmiri et al., 2014). These enable more evidence-based decisions in material selection and design optimization, ultimately reducing complications and enhancing patient satisfaction (Ko et al., 2012).

2.12.1 Key Areas of Investigation in Previous Studies on FEA of PEEK RPDs

In earlier studies, FEA was primarily employed to simulate stress distribution within individual RPD components, such as the major connector, rest, and clasp. These foundational works largely involved conventional metallic frameworks, predominantly CoCr or stainless steel, limiting applicability to newer materials (Richert et al., 2021; Sandu et al., 2010; Sato et al., 2001).

A major focus was on clasp and direct retainer design, aiming to optimize width, length, and cross-sectional geometry to enhance retention while minimizing stress. For example, Sandu et al. analysed wrought wire clasps of different cross-sections, whereas Richert et al. developed an analytical model for CAD-fabricated I-bar clasps (Richert et al., 2021; Sandu et al., 2010). Although these studies provided valuable theoretical understanding, they were restricted to a single material and clasp type. Subsequent studies expanded to multiple clasp configurations, including Akers, reverse Akers, embrasure, I-bar, and back-action designs (Nakamura et al., 2014; Aoda et al., 2010), with later research incorporating 3D patient-derived models for more clinically realistic simulations.

With the emergence of metal-free frameworks, high-performance polymers such as PEEK were investigated as alternatives. Two notable studies focused on PEEK as a direct retainer. Tribst et al. compared multiple materials, including PEEK, polyamide, titanium, gold alloy, and CoCr, using a standardized Akers clasp to assess stress distribution and retention (Tribst et al., 2020). Peng et al. optimized PEEK clasp

geometry, testing 72 variations in width, thickness, and taper ratio, demonstrating that careful design can achieve favourable retention and fatigue resistance, particularly in moderate undercuts (Peng et al., 2020). Although the methodologies differ with Tribst et al., employing a uniform clasp shape and Peng using simplified rod-shaped models, their findings are complementary. Tribst et al., offered a broad material comparison, while Peng et al., provided detailed guidance for PEEK-specific design optimization. Both studies highlight the need for clinical validation of FEA findings, especially regarding long-term fatigue resistance and abutment tooth interactions. Both studies noted less permanent deformation in PEEK compared to CoCr after cyclic loading, highlighting its potential clinical viability.

FEA research also addressed major connector design, often tailored to Kennedy classifications and palatal vault morphologies. CoCr frameworks remain the most rigid, while thermoplastics and PEEK offer flexibility and reduced mucosal stress (Hallikerimath et al., 2015; Bhojaraju et al., 2014). Most of these focused on CoCr frameworks, though a few compared other materials, such as thermoplastic nylon, titanium, and PEEK (Rodrigues et al., 2021; Chen et al., 2019; Ramakrishnan & Singh, 2010). The general consensus supports CoCr as the most rigid and load-bearing option, whereas thermoplastics increase stress on abutments. However, Chen et al. demonstrated that PEEK, while more flexible, produces lower periodontal stress, suggesting potential benefits in patients requiring stress relief on periodontally compromised abutment teeth (Chen et al., 2019).

Among mandibular frameworks, Chen et al. conducted one of the most comprehensive analyses, comparing CoCr, titanium, and PEEK across four framework designs. Using CBCT-derived 3D mandibular models, the study integrated anatomical detail with mechanical simulation, assessing not only framework stress but also effects on the PDL and mucosa (Chen et al., 2019). Despite focusing solely on the lingual plate connector, the study provided valuable insights into PEEK's biomechanical performance and its interaction with oral tissues, establishing groundwork for future comparative research involving the lingual bar as the more commonly used design.

Additionally, limited research has explored PEEK occlusal rests using FEA. One study evaluated PEEK and zirconia under 100 N vertical loading, finding that while zirconia demonstrated superior fatigue strength, modifying PEEK occlusal rests by increasing their dimensions (minimum thickness of 1.5 mm, width of 3.0 mm) and adopting a larger radius of transitional curvature (≥ 0.5 mm) effectively reduced stress

concentrations, meeting flexural strength requirements (Lyu et al., 2023). Although these findings offer practical design recommendations, this approach remains a simulated solution. Clinically, enlarging rest seats requires additional removal of tooth structure, which may compromise dentine thickness and increase the risk of pulpal involvement, factors not accounted for in the FEA model. Therefore, improved stress distribution in simulation may not directly translate into a biologically acceptable clinical outcome.

Despite these advances, several research gaps remain. Most FEA studies use static loading, which does not replicate the cyclic masticatory forces crucial for evaluating long-term material performance. Clinical validation of patient-specific models is still limited, and hybrid designs combining PEEK with metal components remain largely unexplored. Longitudinal clinical studies are essential for confirming FEA predictions and guiding evidence-based PEEK RPD design.

Table 2.8
Finite Element Analysis Studies Related to PEEK Removable Partial Denture

Author, Year	Focus area	FEA approach/Method	Material tested	Design	Author remarks
Lyu et al., 2023	Rest design	3D FEA of occlusal rest models (varied thickness, width, curvature). Load application: Simulated 100 N vertical load (mimicking masticatory load) Analysis: Maximum principal stress (Max-S1) compared to flexural/fatigue strengths.	PEEK Zirconia	Subject: 3D rest models, including the occlusal rest, minor connector, and rest seat models (ie simplified abutment model) Rest design: Following conventional metal occlusal rests (and change in thickness, width, curvature during experimental).	Zirconia has better fatigue strength than PEEK. PEEK occlusal rests showed excessive stress and risk of deformation. Clinical implication: PEEK may not withstand long-term mastication, while zirconia is a viable metal alternative for occlusal rests.
Guo et al., 2022	Stress & strain in mucosa and cortical bone	3D FEA of patient-specific RPDs using CBCT & CAD/CAM. Load application: Simulated 120 N vertical load	PEEK	Case: Maxillary Kennedy Class 1 Design: palatal strap with different manufacturing technique (3D-printed one-piece PEEK RPD, PEEK framework + artificial teeth, and PEEK framework + base plate)	PEEK RPDs showed higher mucosal stress and greater displacement than metal-based RPDs but caused lowest stress on abutments. Clinical implication: PEEK RPDs reduce abutment stress but increase mucosal loading, making them unsuitable for patients with poor soft tissue support.
Peng et al., 2020	Clasp optimization	3D FEA models of PEEK clasps with different thickness/width ratios. Modeled 72 rod-shaped clasp designs with variations in: Load application: Concentrated	PEEK CoCr	Case Type: Not specified (generic clasp design). - Simplified linear elastic model (nonlinear PEEK behaviour not considered). - Straight clasp arms tested (curved	PEEK clasps deformed more initially but stabilized over time. Clinical implication: PEEK clasps can provide sufficient retention, but shape optimization

Author, Year	Focus area	FEA approach/Method	Material tested	Design	Author remarks
		loads at 3 mm from clasp tip (0.25 mm/0.50 mm displacement). - Fatigue Test: Sinusoidal loading at 0.25 mm (both materials) and 0.50 mm (PEEK only)-10 years of RPD use.		clinical designs need evaluation). Designs: PEEK clasps with different taper ratios and base widths. - Thickness/width ratios (0.5–0.875). - Base widths (2.0–3.0 mm). - Taper ratios (0.5–1.0).	is critical to avoid excessive deformation.
Tribst et al., 2020	Stress distribution in clasps	Non-linear contact surfaces FEA in modelled upper molar and Akers clasp using CAD software. Load application: Simulated occlusal displacement (upward force mimicking patient removal). Analysis: Maximum principal stress evaluated in clasp and enamel and failure risk	Polyamide, Polyoxymethylene, PEEK, Gold alloy, Titanium, CoCr.	Aker clasp design 1. Retentive Arm: half-cylinder shape (1.0 mm thickness, ~9 mm length). 2. Reciprocal Arm: flat shape (2.5 mm thickness, ~9 mm length). 3. Occlusal Rest: Mesially positioned, filling a prepared rest seat (4.3 × 2.8 × 3 mm). Undercuts Tested: 0.25 mm, 0.50 mm, and 0.75 mm.	Stress Concentration: Highest at clasp tip and enamel contact area, exacerbated by rigid materials (e.g., CoCr) and larger undercuts. Retention Force: Directly proportional to material rigidity and undercut size. Failure Risk: Polyamide had the lowest enamel failure risk (0.11 at 0.75 mm undercut), while CoCr caused enamel stress > yield strength (1.10 failure risk)
Chen et al., 2019	Abutment teeth, mucosa and framework mechanical function	3D non-linear FEA models based on CBCT data. Simulated 4 RPD designs with different framework materials Accurate mucosa reconstruction by combining CBCT and master model scan data (avoiding	PEEK, CoCr Ti	Subject: 35, Chinese, Male Case: Mandibular Kennedy Class 2 modification 1 Design: combination RPT, RPI, Aker, arrow clasp	PEEK had the lowest stress on PDL (protective for abutments) Higher stress on mucosa and greater displacement in PEEK frameworks.

Author, Year	Focus area	FEA approach/Method	Material tested	Design	Author remarks
		uniform thickness assumption). Load application: Simulated 120 N vertical load			Clinical recommendation: PEEK may be beneficial for patients with poor periodontal conditions but not ideal for free-end RPDs due to instability.

2.12.2 Future Directions of FEA Studies in RPDs

Future research in finite element analysis (FEA) for RPDs is expected to focus on improving model accuracy, incorporating dynamic loading, and integrating patient-specific data. One important direction is developing individualized FEA models using CBCT scans and digital workflows, allowing precise simulations tailored to each patient (Chen et al., 2019; Kouhi et al., 2024). Currently, most evidence is simulation-based with limited in vivo validation. Combining patient-specific FEA with clinical trials; for example, comparing PEEK and metal frameworks could strengthen the link between computational predictions and clinical outcomes.

Multi-physics simulations that combine FEA with computational fluid dynamics or muscle force modeling offer another promising opportunity. These approaches can better capture chewing dynamics and predict long-term fatigue behaviour (Rodrigues et al., 2021; Sharma & Sharma, 2025). Additionally, incorporating nonlinear and viscoelastic properties for the PDL and mucosa, as well as hyperelastic soft tissue models, can provide more realistic stress distributions and clarify the role of supporting tissues in load transmission (Su et al., 2013; Wakabayashi et al., 2008).

Finally, advances in machine learning and AI-driven FEA models may enable performance prediction using large datasets and facilitate more efficient design optimization (Iosif et al., 2024; Ali et al., 2023). Nevertheless, experimental and clinical validation will remain essential to translate computational advancements into practical, evidence-based prosthodontic applications. These innovations could lead to more durable, biomechanically optimized RPDs that improve patient comfort and oral health.

2.13 Chapter Summary

In summary, the literature highlights that both biomechanical and biological challenges contribute to the deterioration of terminal abutment teeth in RPD wearers. While rigid CoCr frameworks have long demonstrated favourable stress distribution, limitations related to fabrication complexity and aesthetics have led to growing interest in polymer-based alternatives such as PEEK. However, current evidence on PEEK frameworks is predominantly derived from laboratory and in vitro studies, with limited validation of their biomechanical predictions in a clinical setting. Furthermore, although FEA has emerged as a valuable tool for simulating stress behaviour in RPDs, the

translation of these computational models into practical biological outcomes remains insufficiently documented. These gaps in the literature justify a comprehensive approach that integrates FEA and clinical evaluation to determine how framework material properties influence the prognosis of terminal abutment teeth. This dual methodology forms the foundation of this present study.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Chapter 3 presents the study's methodology. This section will be divided into two parts, which are the finite element analysis (FEA) study and the clinical study.

3.2 Ethical Approval

Ethical approval was obtained from Universiti Teknologi MARA (UiTM) ethical committee REC/08/2023 (PG/FB/14) (Appendix 1). Subjects were informed of the nature of the study, and written informed consent was obtained before enrolment.

Although the study is classifiable as a prospective clinical study, formal registration in a clinical trial registry was incomplete prior to commencement. This is acknowledged and addressed as a limitation of the study. Nevertheless, the study was approved by the institutional ethics committee, followed a clearly defined protocol, and was conducted in compliance with ethical and clinical standards.

3.3 Stages of Study

This study was conducted in two main stages. Following ethical approval for both stages, the first stage involved an FEA to evaluate the mechanical properties and stress distribution in RPDs with PEEK and CoCr frameworks. In the second stage, a clinical study was conducted to compare the effects of these materials on terminal abutment teeth, both clinically and radiographically. Figure 3.1 illustrates the research workflow of the study.

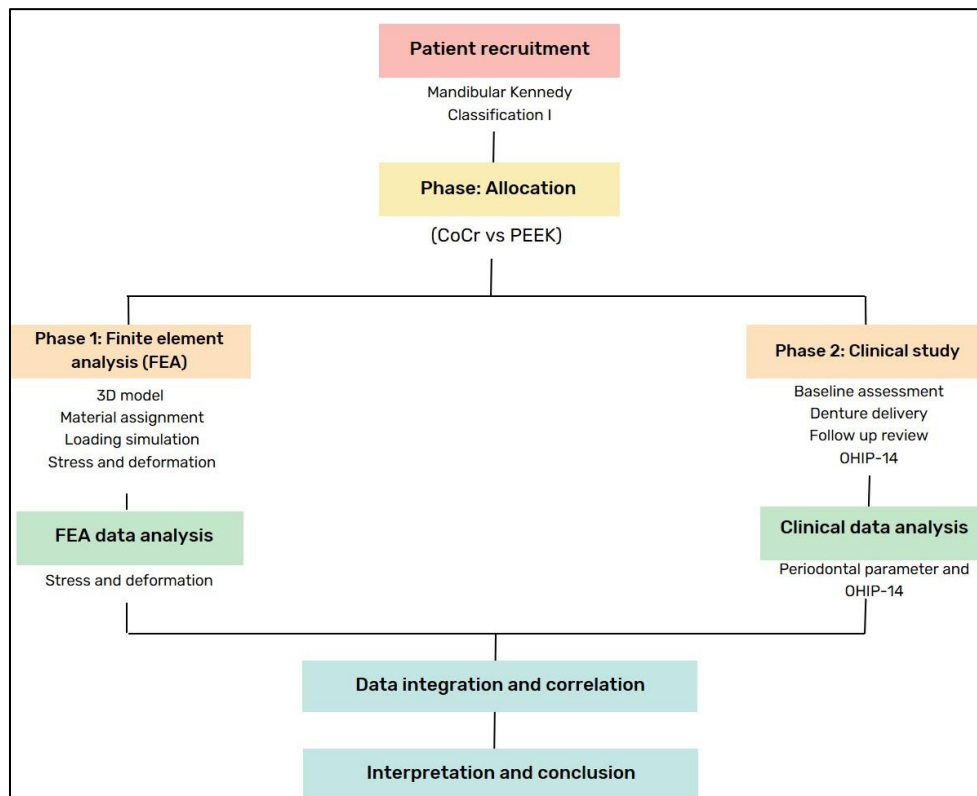


Figure 3.1 Research Workflow for Biomechanical and Clinical Evaluation of CoCr and PEEK RPD

3.4 Finite Element Analysis

Finite element analysis (FEA) is a numerical method that can be used to explore and simulate the biomechanics of a removable prosthesis in the oral cavity (Kibi et al., 2009; Shahmiri et al., 2014). The FEA analysis was conducted in reference to Chen et.al, 2015 study of the influence of different designs of RPDs using PEEK as RPD framework material on the patient's oral tissues in comparison to CoCr, titanium alloys and PEEK framework (Chen et al., 2019).

3.4.1 Study Setting

The FEA was conducted at laboratory in Mechanical Engineering Faculty, Universiti Teknologi MARA, Shah Alam. Model scanning and denture design were carried out at the Faculty of Dentistry, Universiti Sains Islam Malaysia. This FEA study was conducted in four phases, which are: 3D modelling data for the mandibular bone,

remaining teeth, and master model, 3D modelling of the RPD framework, simulation of the stress distribution by occlusal masticatory force, and data analysis.

3.4.2 Sample Size Calculation

For objectives 1 and 2. To compare the biomechanics of a polymer-based PEEK framework to the metal-based CoCr framework for an RPD through finite element analysis. A median-build subject with mandibular bilateral distal extension who comes for implant treatment was used in this study. As the patient does not have enough bone for an implant (based on an investigation with a cone beam tomography system) (CBCT), an RPD was made, and the patient was recruited to become a participant in this study (Chen et al., 2019).

3.4.3 Patient Selection

Following ethical approval, a 67-year-old Malay male patient with a medium build and bilateral mandibular distal extension was included in this study. The patient initially sought implant therapy; however, CBCT assessment revealed insufficient bone volume for implant placement. Consequently, rehabilitation using an RPD was planned, and the patient was invited to participate in the research. The patient was medically healthy, with no relevant systemic diseases or signs of severe periodontal pathology. Mild mandibular ridge resorption was noted in the region of teeth 35–45, while all remaining teeth were intact and periodontally stable. The nature and objectives of the study were clearly explained to the patient, and written informed consent was obtained prior to participation.

3.4.4 Finite Element Modelling

3.4.4.1 Bone and Teeth Geometry

Cone beam clinical Tomography (CBCT) data and master model were scanned from a patient with a mandibular bilateral distal extension case, and a 3-dimensional FEA solid model was developed (Figure 3.2). The mandibular bone was scanned with CBCT (CS 9600 CBCT Scanner, Carestream) at a 0.25-mm-slice thickness and 1-mm

scan increment in 401 slice images in DICOM format. Mandibular geometry was reconstructed by converting raw CBCT scan data into a 3D model (Figure 3.3), followed by transformation into a CAD file using reverse engineering techniques.

The images were imported into the software to obtain the mandibular bone model and the remaining teeth models. The output data were imported into Mimics (Mimics 17.0, Materialise NV), where they were processed and segmented to isolate the anatomical structures of interest, including the mandibular bone, teeth, and associated tissues. The CBCT images were exported in DICOM format and processed for segmentation to isolate anatomical structures of interest, including the mandible, teeth, and associated tissues. Segmentation is the process of separating a region of interest from adjacent regions that represent different anatomical structures, such as enamel, dentin, or cortical and cancellous bone, based on their radiodensities expressed in Hounsfield Units (HU). The segmentation of mandibular structures, including cortical bone, cancellous bone, and tooth dentin, was performed using Materialise Mimics software.

For cortical bone segmentation, it was segmented using a high-density threshold range (>850 HU), while cancellous bone was extracted using a lower threshold range (150–600 HU) and refined by subtracting the cortical bone mask to avoid overlap. Tooth dentin was segmented separately using a higher threshold value (>1000 HU) to isolate the denser dental structures. Region growing, manual editing, and Boolean operations were employed to refine the masks, and each segmented structure was converted into a 3D model using the “Calculate 3D” function for subsequent analysis. Figure 3-4 summarized the information obtained from CBCT for FEA.

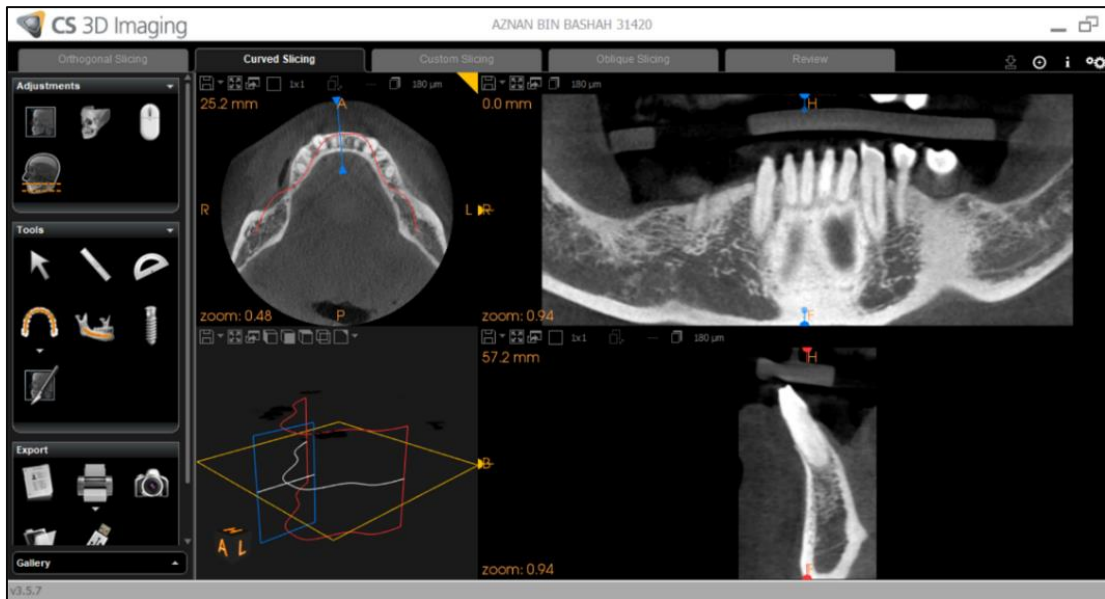


Figure 3.2 Example of Cone Beam Clinical Tomography (CBCT) of Patient.

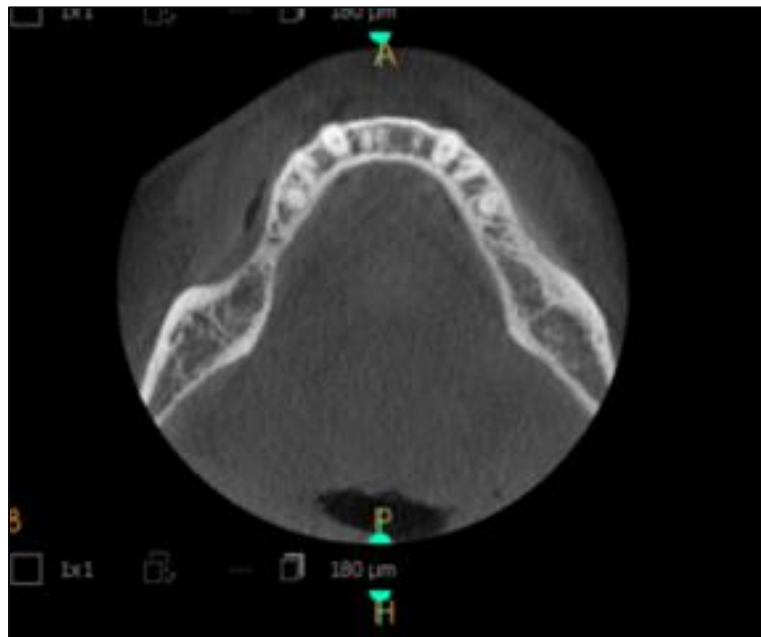


Figure 3.3 Raw Cone Beam Clinical Tomography Scan Prior to Converting to 3D Model Using Reverse Engineering Techniques.

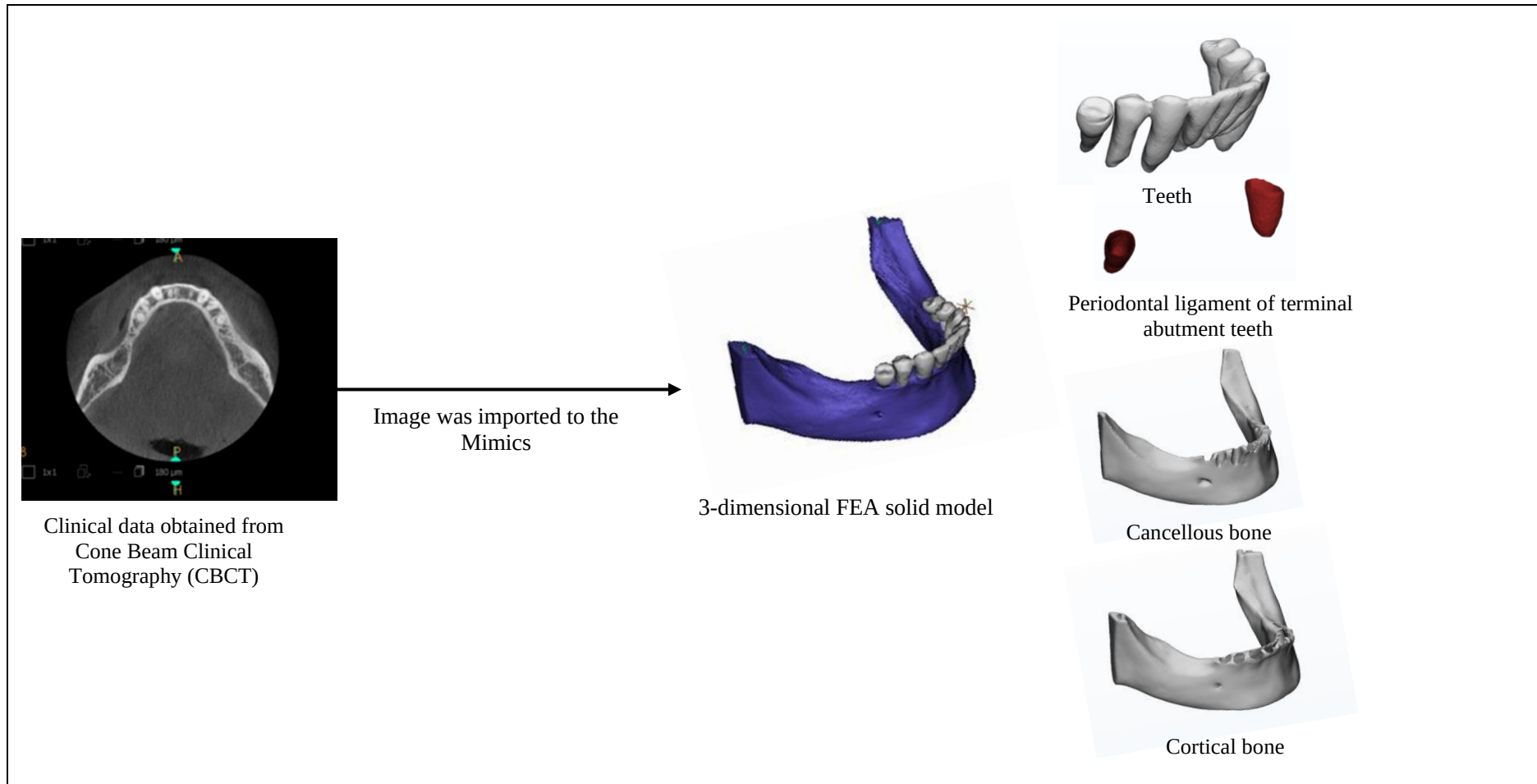


Figure 3.4 Information Obtained from Cone Beam Clinical Tomography (CBCT) for Finite Element Analysis; Cortical Bone, Cancellous Bone, Periodontal Ligament of Terminal Abutment Teeth and Teeth.

3.4.4.2 Soft Tissue Geometry

A mandibular impression was taken using alginate material, and a master model was subsequently fabricated in dental plaster. The external surface of the plaster model was scanned using a desktop scanner (3Shape D2000, USA) to generate a 3D model of the coronal portions of the remaining teeth and the soft tissue in the edentulous areas (Figure 3.5). The resulting data were saved as a point cloud object in stereolithography (STL) format (.stl) (Figure 3.6).

Following the segmentation of mandibular hard tissues, the mucosa model was developed using Materialise 3-matic software. The cortical bone STL was imported, and the mucosal layer was generated by applying the “wrap function” with a gap closing distance set between 1–2 mm to simulate the natural soft tissue thickness over the alveolar ridge and surrounding areas. The wrapped surface, representing the outer contour of the mucosa, was then converted into a watertight 3D model and remeshed to ensure mesh quality suitable for subsequent finite element analysis.

The periodontal ligament (PDL) was modelled in 3-matic by offsetting the tooth root surface by 0.2 mm to create a uniform layer (Ahmad et al., 2020). The resulting geometry was converted into a solid and remeshed for simulation use.

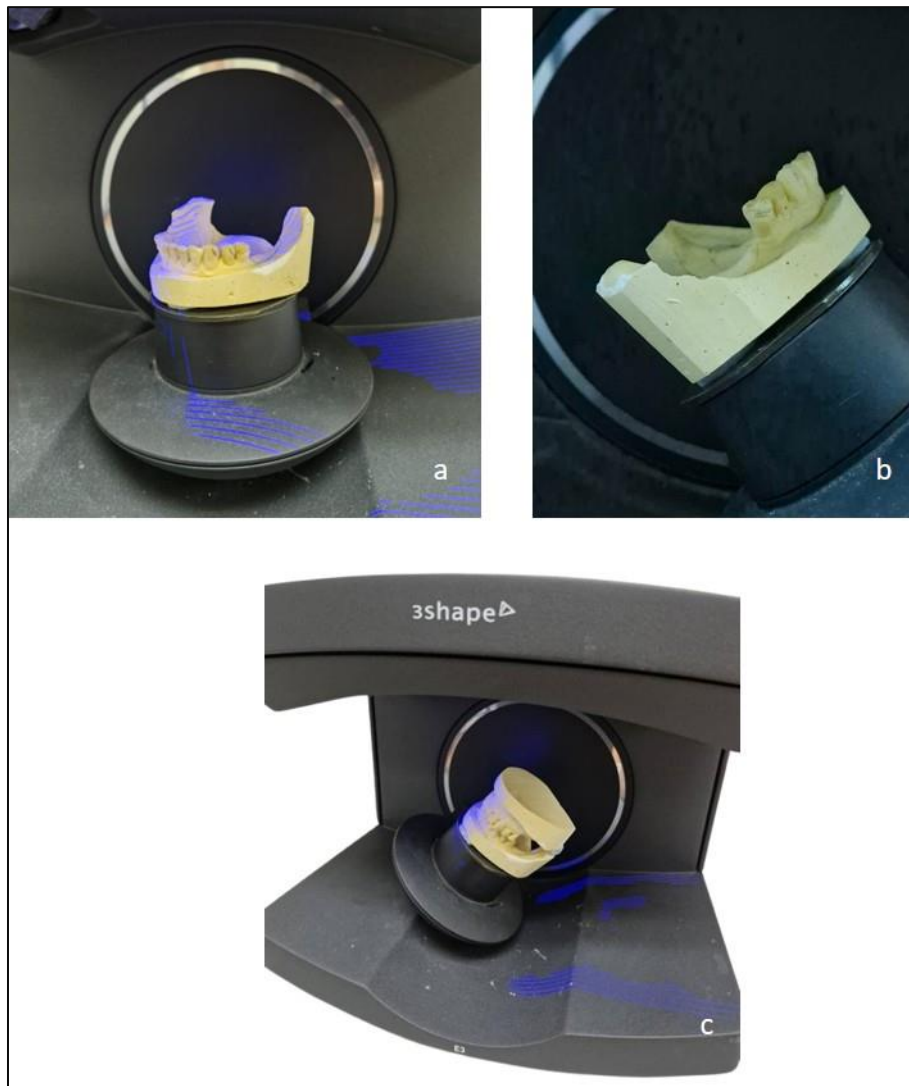


Figure 3.5 a-c Scanning Procedure of the Master Model Using the 3Shape D2000 Desk Scanner (USA)

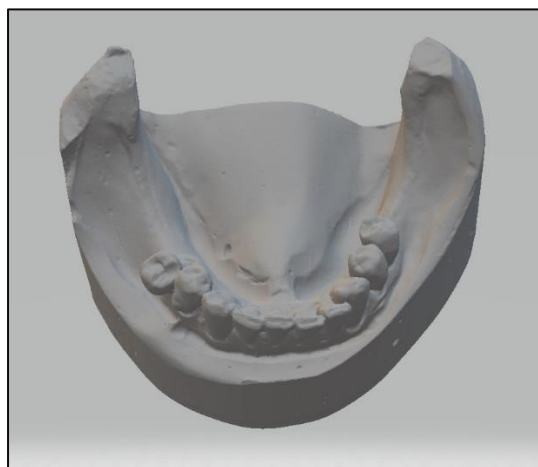


Figure 3.6 A 3-Dimensional Digital Model of the Mandibular Arch in Stereolithography (.stl) File Format

3.4.4.3 Removable Partial Denture Geometry

The 3D model of the RPD framework was created on the scanned plaster model using the 3Shape Dental System™ software (Dental System 2017, Denmark). The process began by importing the 3D digital scan of the master model (in. stl format) into the software.

The first step involved identifying and selecting the denture teeth by marking the positions of the missing teeth and specifying the abutments, which in this case were teeth 36 and 46. Once the denture teeth were selected and marked, their shape and size were adjusted to meet the design requirements, including modifying the contours of the denture teeth. After finalizing the design, the digital file was validated for any issues and then exported (typically in stl.format) for FEA (Figure 3.7).

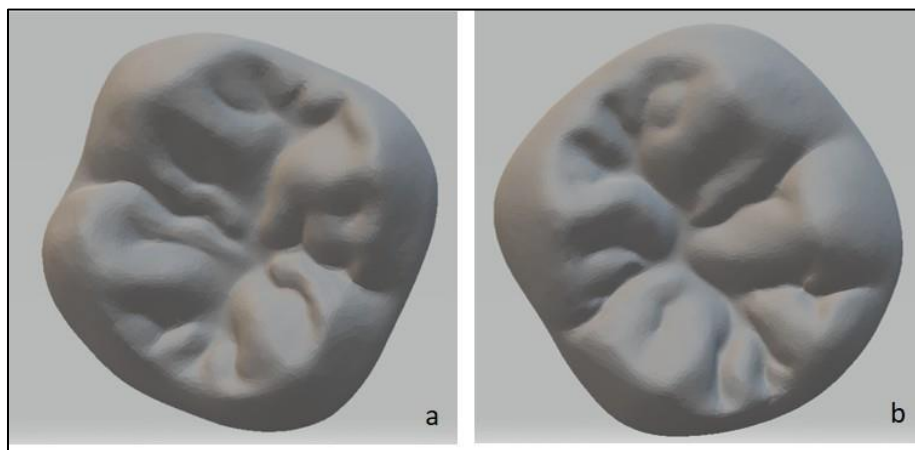


Figure 3.7 Abutment Teeth of 36 (a) and 46 (b) in Stereolithography (.stl) Files Format

In accordance with standard design specifications for RPDs, four types of RPD were designed by an experienced prosthodontist using 3Shape software. After the digital scan of the master model is obtained, the design begins by evaluating the path of insertion, which determines how the RPD will fit onto the abutment teeth and underlying soft tissues. The 3Shape software enables the clinician and dental technician to manipulate the digital model and select the optimal insertion path, thereby avoiding potential interference from undercuts.

During this phase, retention areas are mapped, typically identifying undercuts on the abutment teeth, particularly premolars, that will be engaged by the clasps for adequate retention. The design process flows systematically, starting with the creation

of the saddle, followed by the major connector, then the rests, and finally the clasps, ensuring all elements of designing the RPD were done (Figure 3.8 until Figure 3.13).

Two variations of the major connector were created: the lingual plate, which extended vertically to cover the lingual surfaces of the anterior teeth with a thickness of 1.0 mm; and the lingual bar, which was modelled with a half-pear cross-section, measuring 5 mm in height and 2 mm in thickness, and positioned at least 4 mm away from the gingival margins (Phoenix et al., 2003).

Mesial or distal occlusal rests were designed on teeth 35 and 45 to provide vertical support. Each rest seat was triangular or spoon-shaped, approximately 2.0 mm buccolingually, 1.5 mm mesiodistally, and 1.5 mm deep, thereby directing loads along the long axis of the abutments (Phoenix et al., 2003). For the lingual bar major connector, the cingulum that rests on both canines was incorporated to stabilize the prosthesis and prevent tissue displacement.

Circumferential clasps (Akers clasps) were placed on the buccal surfaces of the same abutment teeth, originating from the mesial or distal minor connector adjacent to the rest. The clasp arms had a half-round cross-section with reciprocation was achieved not through a lingual arm but via a proximal plate (rigid guiding plate), which also served to stabilize the framework during function (Phoenix et al., 2003). In summary, four different framework designs were developed for the FEA analysis. Figure 3.14 illustrates the four distinct framework designs in .stl files

- i. Lingual plate with Aker clasps and mesial rest on both premolar as terminal abutment teeth
- ii. Lingual plate with Aker clasps and distal rest on both premolar as terminal abutment teeth
- iii. Lingual bar with Aker clasps and mesial rest on both premolar as terminal abutment teeth
- iv. Lingual bar with Aker clasps and distal rest on both premolar as terminal abutment teeth.



Figure 3.8 The Digital Surveying Process is Performed in the 3Shape Dental System

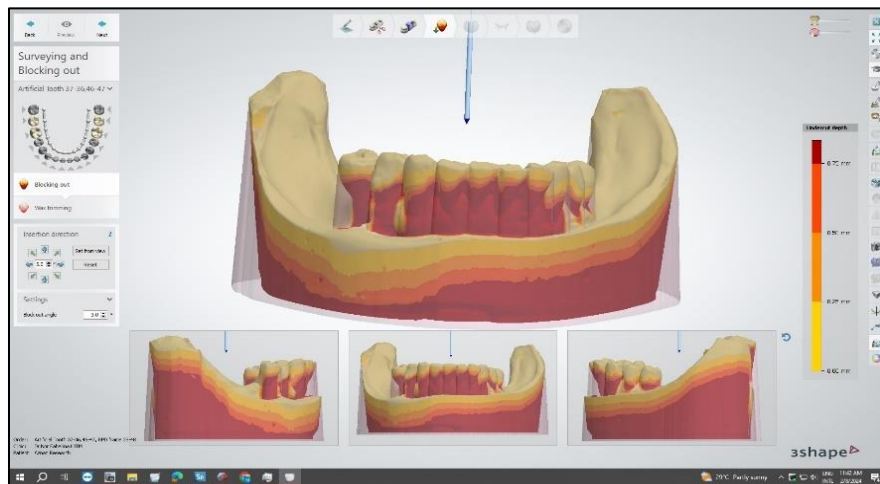


Figure 3.9 Process of Blocking Out Undesirable Undercuts on the Master Model to Prevent Interference with RPD Placement and Removal and to Optimize the Framework's Fit

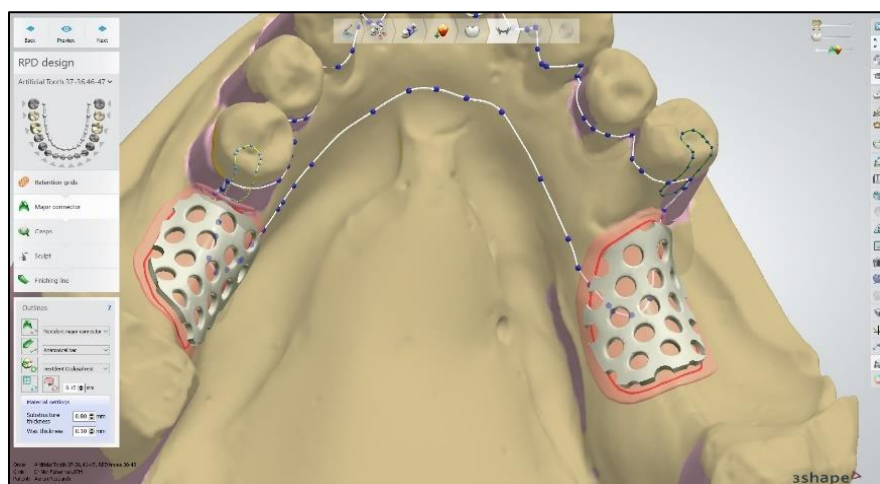


Figure 3.10 Outlining the Saddle Area and Designing the Major Connector

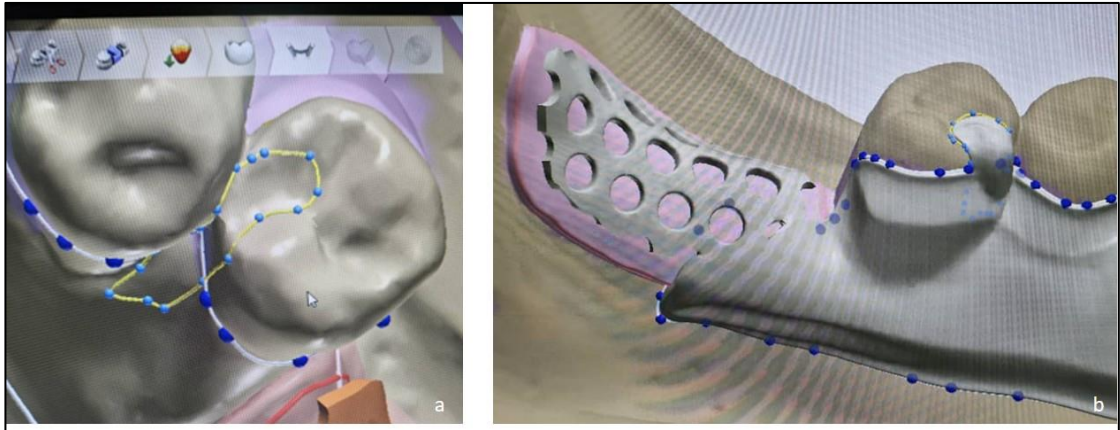


Figure 3.11 a- Rest seat Design: Spoon-shaped, Approximately 2.0 mm Wide Buccolingually, 1.5 mm Long Mesiodistally, and 1.5 mm Deep. b- Completed Rest Seat

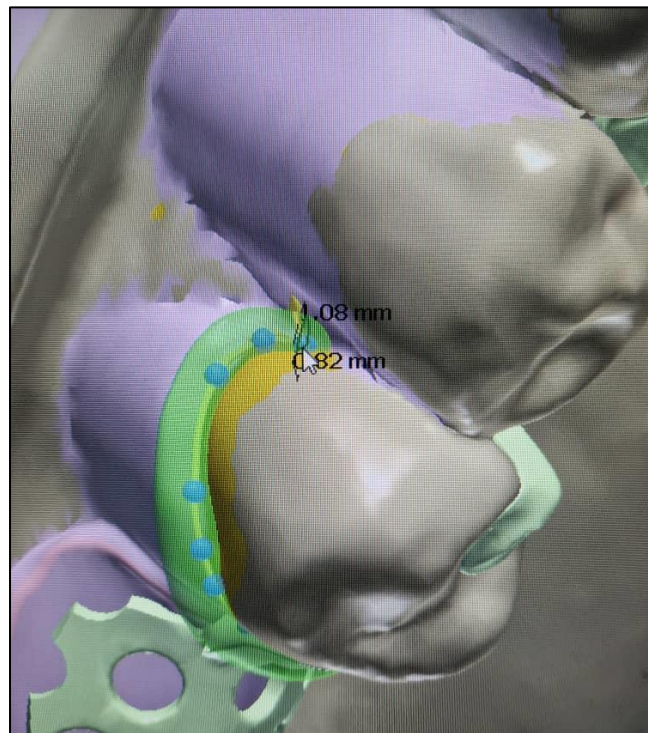


Figure 3.12 Virtual Designing of the Clasp Assembly

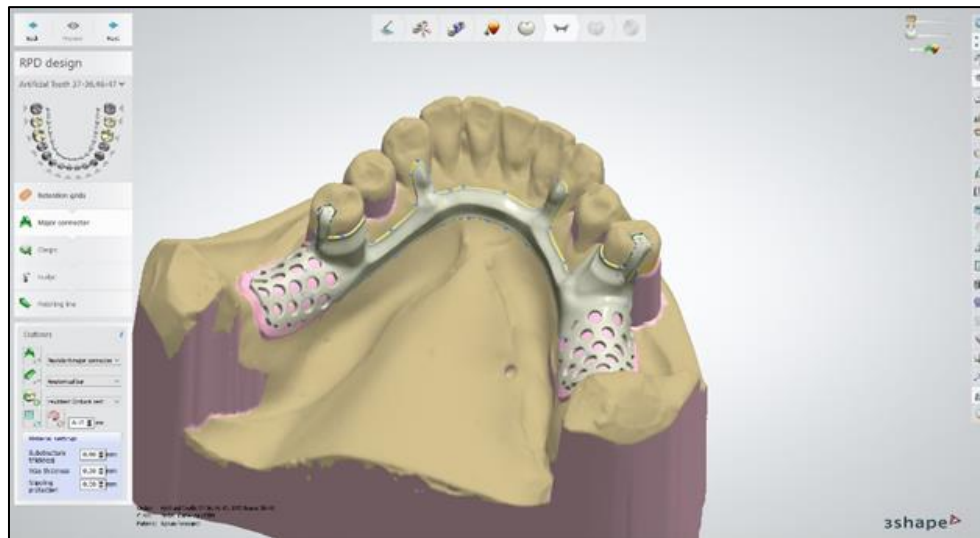


Figure 3.13 The Completed Digital Design of the RPDs Featuring All Key Components, Including the Clasps, Major Connector, Saddle Areas, and Rest Seats

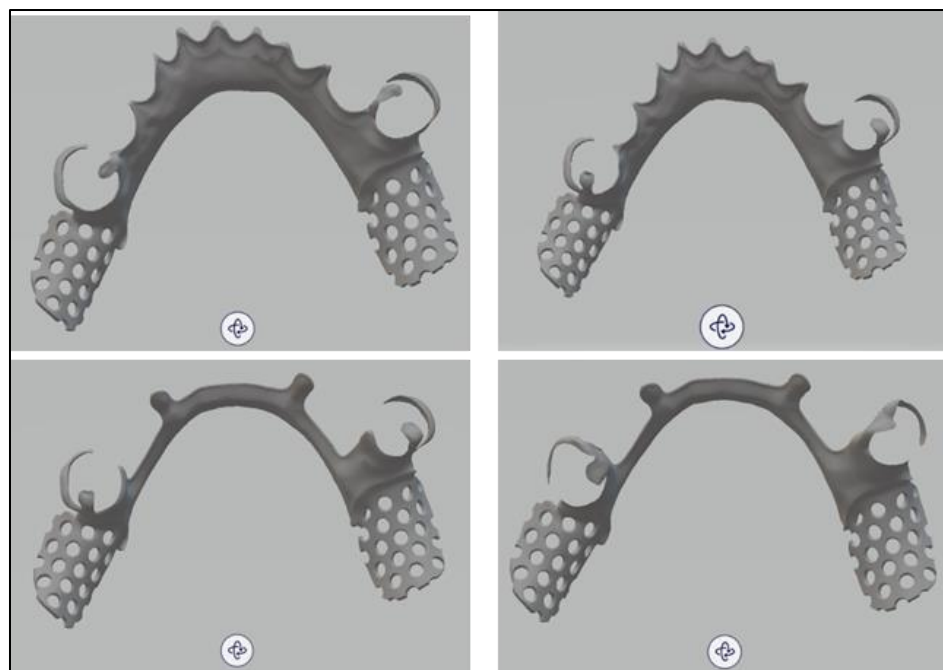


Figure 3.14 Four Distinct Denture Designs, each Featuring Different Major Connector Types and Rest Seat Positions. Two Designs Showcase Major Connectors Such as a Bar and Plate, while the Rest Seats Vary Between Mesial and Distal Positions on the Abutment Teeth

3.4.4.4 Baseplate Geometry

Due to the absence of a specific command for baseplate (flange) design within the 3 Shape Dental System software, a modification approach was adopted using the

"custom tray" function. Designing the flanges first required creating the artificial teeth and framework, which act as guides for the subsequent steps of designing and contouring the flanges. In order to integrate the .stl files of the artificial teeth and framework into the workflow, the "additional scans" loading function was use and the "move" function tool was utilize to realign the framework and artificial teeth (Figure 3.15 and Figure 3.16). These components serve as critical references to optimize the design of the denture flanges, particularly in areas close to the natural abutment teeth. The sculpt toolkit is employed and was used to fill the space between the artificial teeth and framework, to accurately sculpt the gingival anatomy. Adjust the filling as required to achieve the desired outcome (Figure 3.17). The completed design is shown in Figure 3.18. Once satisfied with the design, generate the STL file for the denture baseplate for FEA (Figure 3.19).



Figure 3.15 Integration of .stl Files of Abutment Teeth and Framework and Realignment Using Move Functions

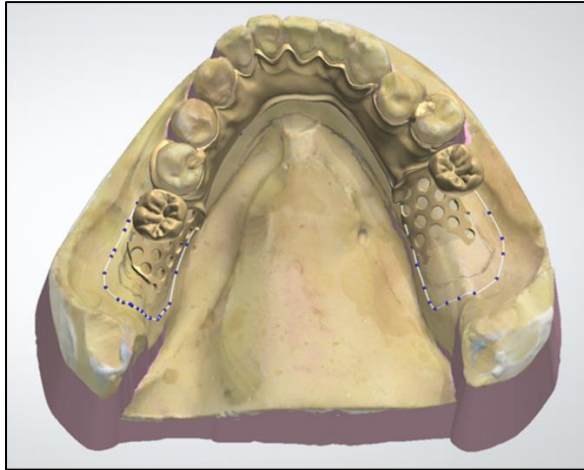


Figure 3.16 Initiation of Denture Flange Design, Shown with Blue Dotted Lines, Using the Custom Tray Mode. For Cases Involving Both Arches, the Flanges Extend Across the Midline

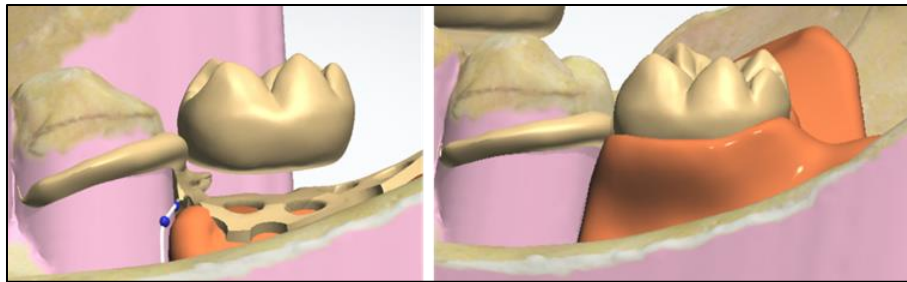


Figure 3.17 a. Initial Design b. Space between Artificial Teeth and Framework is Filled Utilizing the Sculp Toolkit

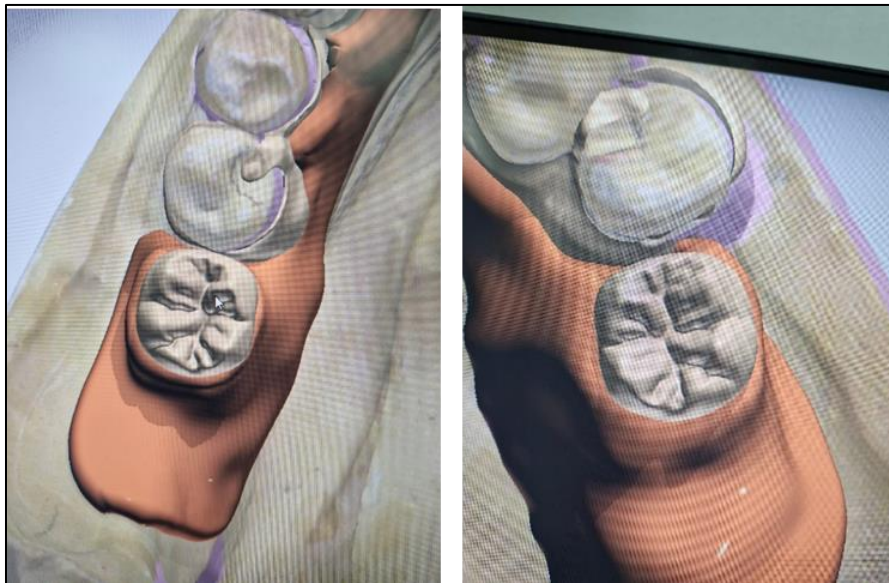


Figure 3.18 The Completed Baseplate Design Seen from the Occlusal View

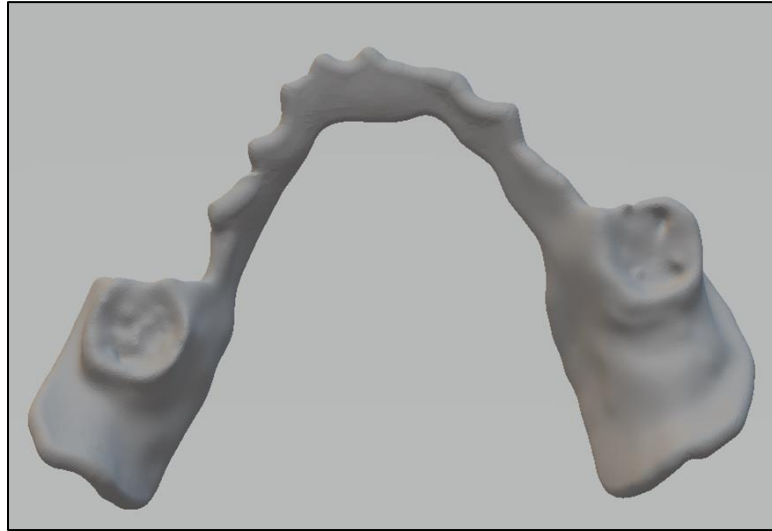


Figure 3.19 The Final Denture Baseplate Design in .stl file

Figure 3-20 summarized the information obtained from digitalized master model for finite element analysis. Final component of modelling is shown in Figure 3-21. The framework, denture base, and denture teeth were developed and imported into 3-matic based on the anatomical geometry of the segmented mandibular model. These components were designed and assembled to ensure proper adaptation to the mucosa and residual ridge. The overall denture structure was aligned and integrated with the mandibular arch to form a complete prosthetic assembly.

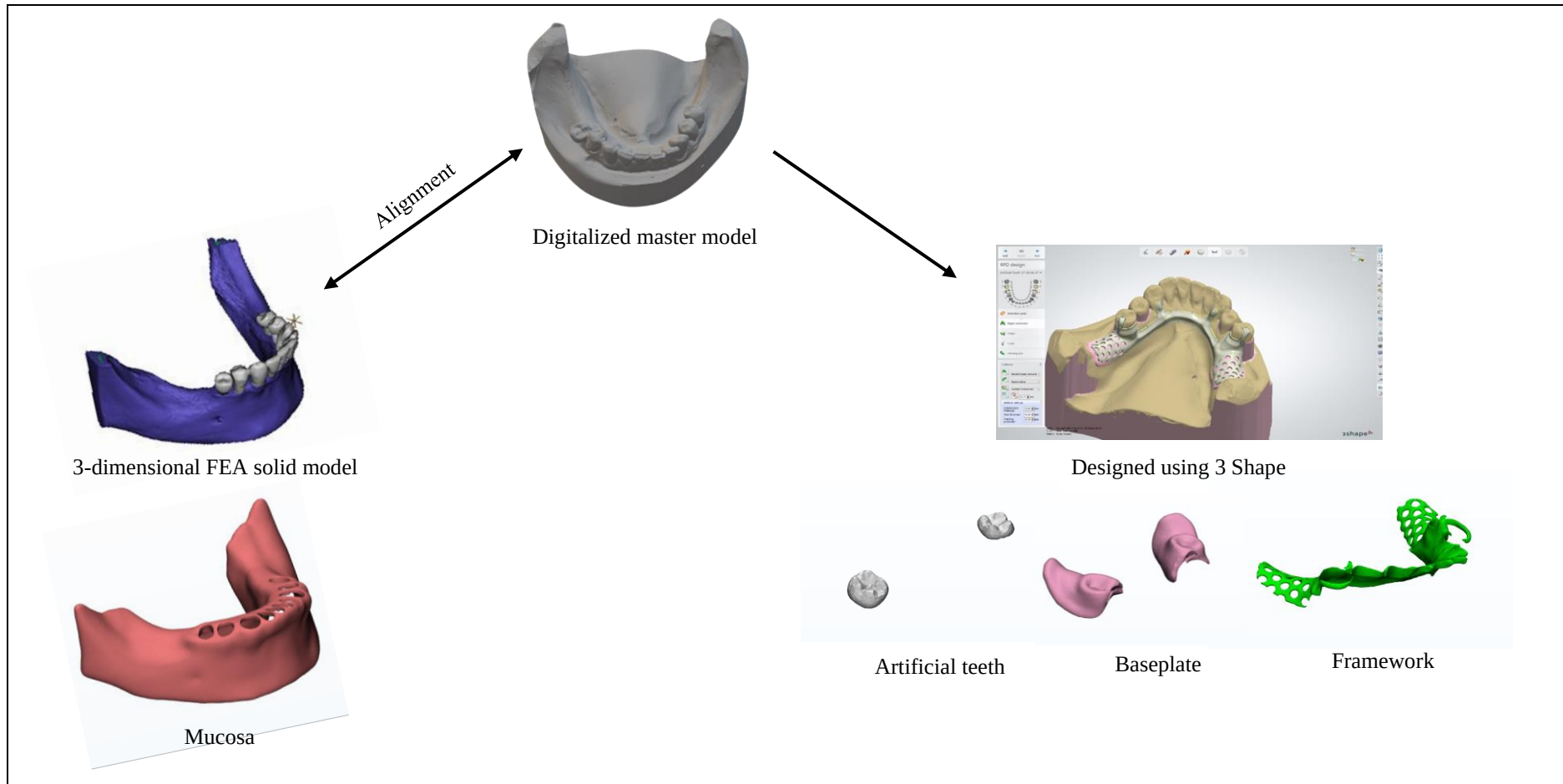


Figure 3.20 Information Obtained from Digitalized Master Model for Finite Element Analysis; Mucosa, Artificial Teeth, Baseplate and Framework

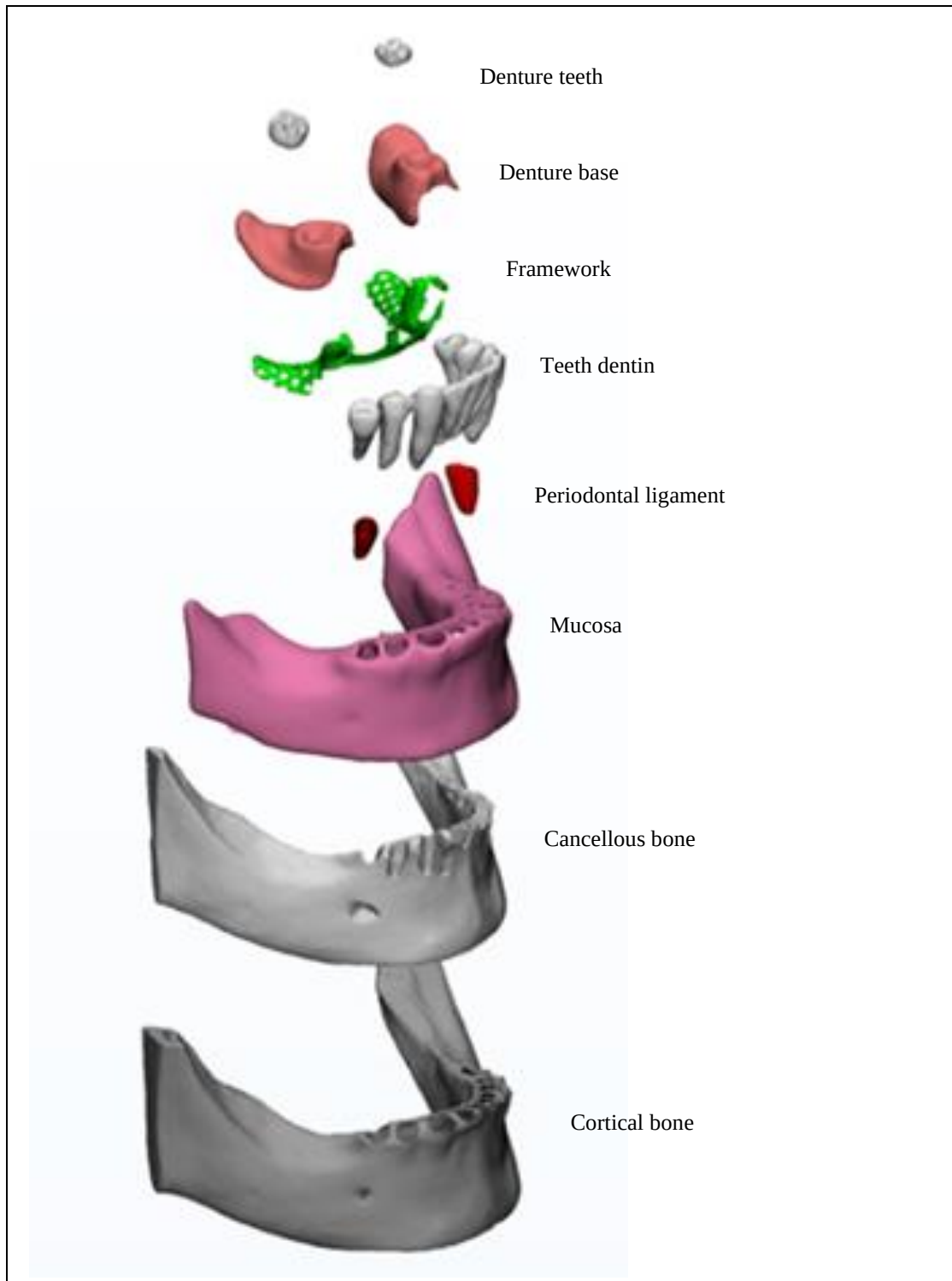


Figure 3.21 Final Modelling for Finite Element Analysis

3.4.5 Element Meshing

The reconstructed 3D model (Figure 3.22) was exported to 3-Matic software for meshing. The meshing process was performed in Materialise 3-matic (13.0, Materialise

N.V, Belgium), where each anatomical and prosthetic component was independently processed to generate high quality tetrahedral volume meshes. Surface defects were first repaired, followed by remeshing and volume mesh generation to ensure accurate geometry representation and mesh integrity. Three mesh densities (coarse, medium, and fine) were developed for convergence testing by adjusting the global element size within 3-matic.

The resulting mesh models were then exported and imported into ANSYS Workbench 14.0 (ANSYS Inc., Canonsburg, PA, USA), for finite element simulation. Mesh statistics presented below correspond to the medium density configuration used for the main analysis. A convergence test was conducted by comparing the maximum Von Mises Stress values obtained from three different mesh densities of the Design 1 PEEK framework assembly. The meshes used were coarse, medium, and fine, each generated in 3-matic and imported into ANSYS Workbench for analysis. The number of elements for each mesh density was 182718 for the coarse mesh, 388519 for the medium mesh, and 727948 for the fine mesh. The stress values were extracted from a consistent region of interest under the same loading and boundary conditions to evaluate mesh sensitivity and determine the optimal balance between accuracy and computational efficiency.

Following the convergence test, the medium mesh was selected for all subsequent analyses as it provided an optimal balance between computational efficiency and accuracy, with minimal difference in stress values compared to the fine mesh. Ideal meshing quality was achieved through optimization techniques, ensuring accurate FEA. The meshing process was carefully adjusted to balance precision and computational efficiency (Figure 3.23) The number of nodes and elements generated in the mesh were recorded, as in Table 3.1.

Table 3.1
Number of Nodes and Elements

Design	Nodes	Element
Design 1	902466	477628
Design 2	560195	293168
Design 3	918765	485446
Design 4	923901	489676

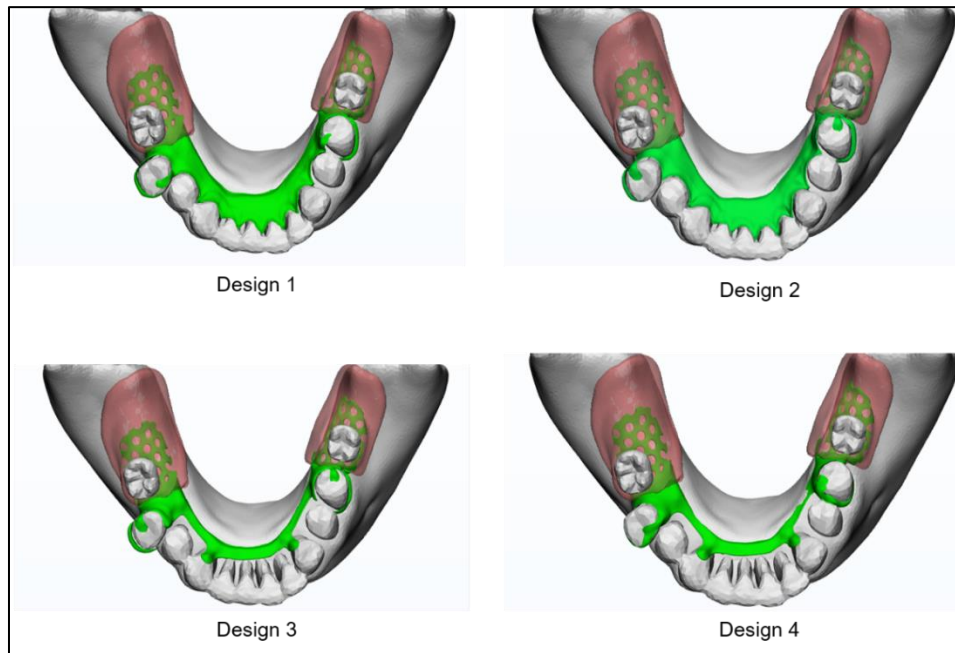


Figure 3.22 Model Assembly and Reconstruction of 3D Model with Different Framework Designs and Rest Seats Positions Prior to Meshing

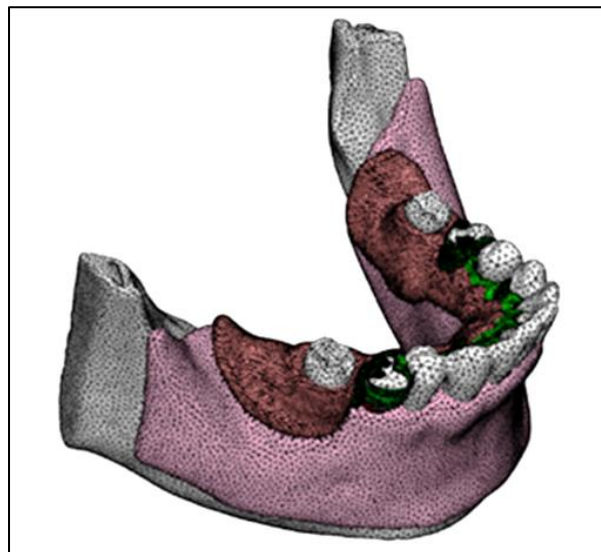


Figure 3.23 Model After Meshing

3.4.6 Material Assignment and Model Import

Although the majority of previous finite element studies have assumed linear elastic material properties, such simplifications may not sufficiently capture the complex biomechanical behaviour of oral tissues particularly the mucosa and periodontal ligament (Jantaban et al., 2025; Shahmiri et al., 2013). Most biological soft tissues have been shown to exhibit complex, nonlinear, and time-dependent responses

to mechanical stimuli, often undergoing large deformations even under relatively small loads generated by prosthesis. Assuming linear elasticity as a constant material property for the oral mucosa and PDL may therefore result in inaccurate or misleading outcomes (Chen et al., 2019; Kanbara et al., 2012).

In this study all materials except the PDL was assumed to be linearly elastic, homogenous and isotropic to simplify the calculations. As for the PDL, the nonlinear hyper-elastic model was used based on the double linear stress-strain curve of Vollmer's research (Chen et al., 2019). The PDL material exhibits stress-dependent mechanical properties, which are critical for accurately modelling its behaviour under physiological conditions. The modulus of elasticity, (σ) and Poisson's ratio $\nu(\sigma)$ of the PDL vary with the applied stress σ . Specifically, for stress levels below 0.002584 MPa, the modulus of elasticity is $E(\sigma) = 0.07$ MPa with a Poisson's ratio of $\nu(\sigma) = 0.25$. As the stress increases to between 0.002584 MPa and 0.005648 MPa, the modulus of elasticity increases to $E(\sigma) = 0.18$ MPa, and the Poisson's ratio becomes $\nu(\sigma) = 0.30$. For stress levels exceeding 0.005648 MPa, the modulus of elasticity reaches $E(\sigma) = 0.20$ MPa, while the Poisson's ratio further increases to $\nu(\sigma) = 0.35$.

These piecewise functions, as described in Equations 1 and 2, capture the nonlinear elastic behaviour of the PDL and are essential for simulating its response under varying load conditions.

Equation 3.1: Modulus of elasticity ($E(\sigma)$):

$$E(\sigma) = \begin{cases} 0.07 \text{ MPa}, & \text{if } \sigma < 0.002584 \text{ MPa} \\ 0.18 \text{ MPa}, & \text{if } 0.002584 \text{ MPa} \leq \sigma < 0.005648 \text{ MPa} \\ 0.20 \text{ MPa}, & \sigma \geq 0.005648 \text{ MPa} \end{cases} \quad (3.1)$$

Equation 3.2: Poisson's ratio ($\nu(\sigma)$):

$$\nu(\sigma) = \begin{cases} 0.25, & \text{if } \sigma < 0.002584 \text{ MPa} \\ 0.30, & \text{if } 0.002584 \text{ MPa} \leq \sigma < 0.005648 \text{ MPa} \\ 0.35, & \sigma \geq 0.005648 \text{ MPa} \end{cases} \quad (3.2)$$

Each component of the model was assigned material properties based on their respective mechanical characteristics (Table 3-2) (Chen et al., 2019).

Table 3.2
Material Properties of Finite Element Model

Material	Elastic modulus (MPa), E	Poisson Ratio, ν
Mucosa	3.45	0.45
Denture Base	2200	0.31
Cancellous bone	1370	0.30
Cortical bone	13700	0.30
PDL	Non linear	0.45
Tooth dentin	18600	0.30
Denture tooth	1960	0.30
CoCr alloy	235000	0.33
PEEK	4100	0.4

3.4.7 Boundary Conditions and Load Application

The boundary condition was applied at the purple cross-sectional area, representing the cut surface of the mandible. This region was assigned an encastre (fixed support) boundary condition, where all degrees of freedom were constrained (Figure 3.24).

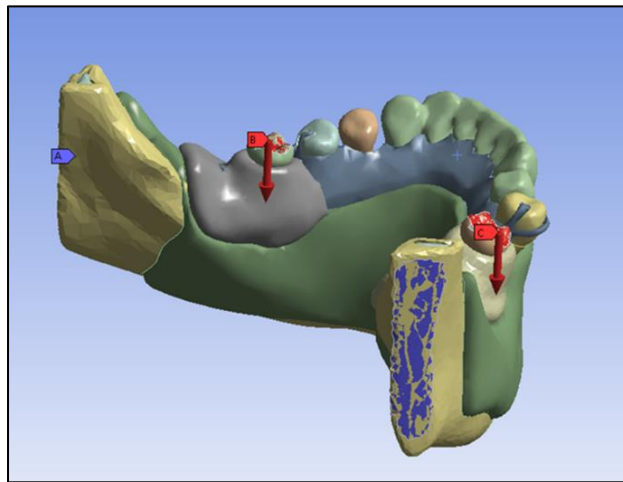


Figure 3.24 The Boundary Condition for FEA is Applied at Cut Surface at the Ramus of Mandible (Purple Cross-sectional Area)

A vertical load of 120 N was applied to the occlusal surfaces of the denture teeth at two contact areas labelled A and B (Figure 3-25 a), representing functional masticatory contacts (Chen et al., 2019). The load was equally distributed between these sites to simulate bilateral mastication. To replicate mandibular fixation during loading,

the posterior sections of the mandibular rami were selected as boundary supports (Figure 3-25 b) and fully constrained in all degrees of freedom. This setup ensured that any observed deformation resulted solely from the mechanical response of the denture components and associated anatomical structures, eliminating any influence from mandibular displacement or rotation.

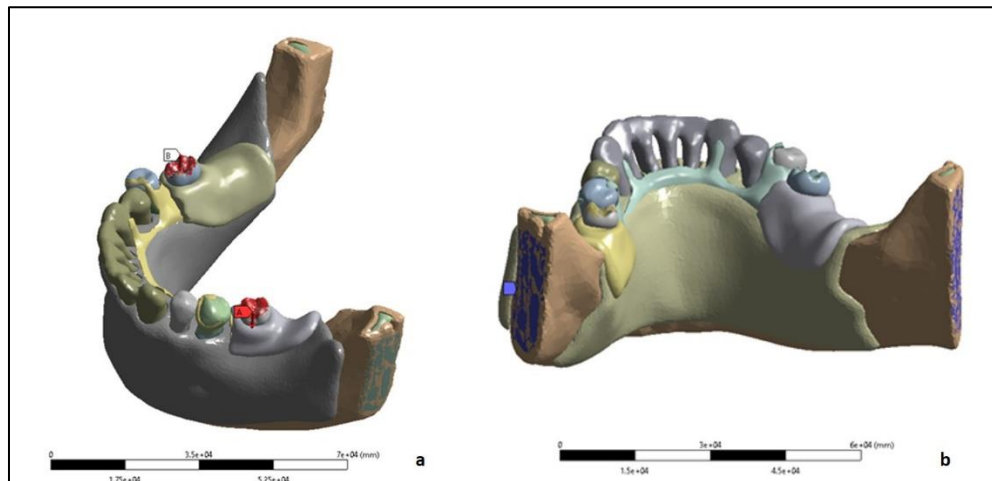


Figure 3.25 a- Location of Applied Vertical Loads (120 N) on Occlusal Surfaces of Denture Teeth at Contact Areas A and B. b- Boundary Conditions: Posterior Mandibular Ramus Sections used as Support During Occlusal Loading

The load application-initiated displacement, allowing realistic contact formation between the denture base and the mucosa. The model evaluated stress and deformation patterns across the RPD framework, PDL, and mucosal tissue. FEA was conducted using ANSYS Workbench to assess biomechanical performance across various denture designs and framework configurations.

The interface between the denture base and mucosa was defined as frictional, with a coefficient of 0.01, based on Sabri et al. (2022), to simulate realistic interaction under functional loading (Sabri et al., 2022). This configuration permitted limited sliding and effective stress transfer at the interface, enhancing the accuracy of biomechanical assessment under vertical force. The FEA in ANSYS was used to evaluate stress distribution and deformation under vertical loading for various denture designs and framework materials. Figure 3.26 shows the flowchart of finite element analysis modelling

3.4.8 Data Reporting and Data Analysis

All finite element simulations were performed using ANSYS Workbench 14.0 (ANSYS Inc). Total deformation (mm) was assessed to determine the displacement of the RPD framework, abutment teeth (PDL), and mucosa, while Von Mises Stress (MPa) was used as the criterion to evaluate the distribution and magnitude of internal stresses within the denture components and supporting structures. Findings were supported by visual outputs (ANSYS contour images) that illustrated biomechanical trends and aided interpretation of the clinical relevance of each design and material configuration.

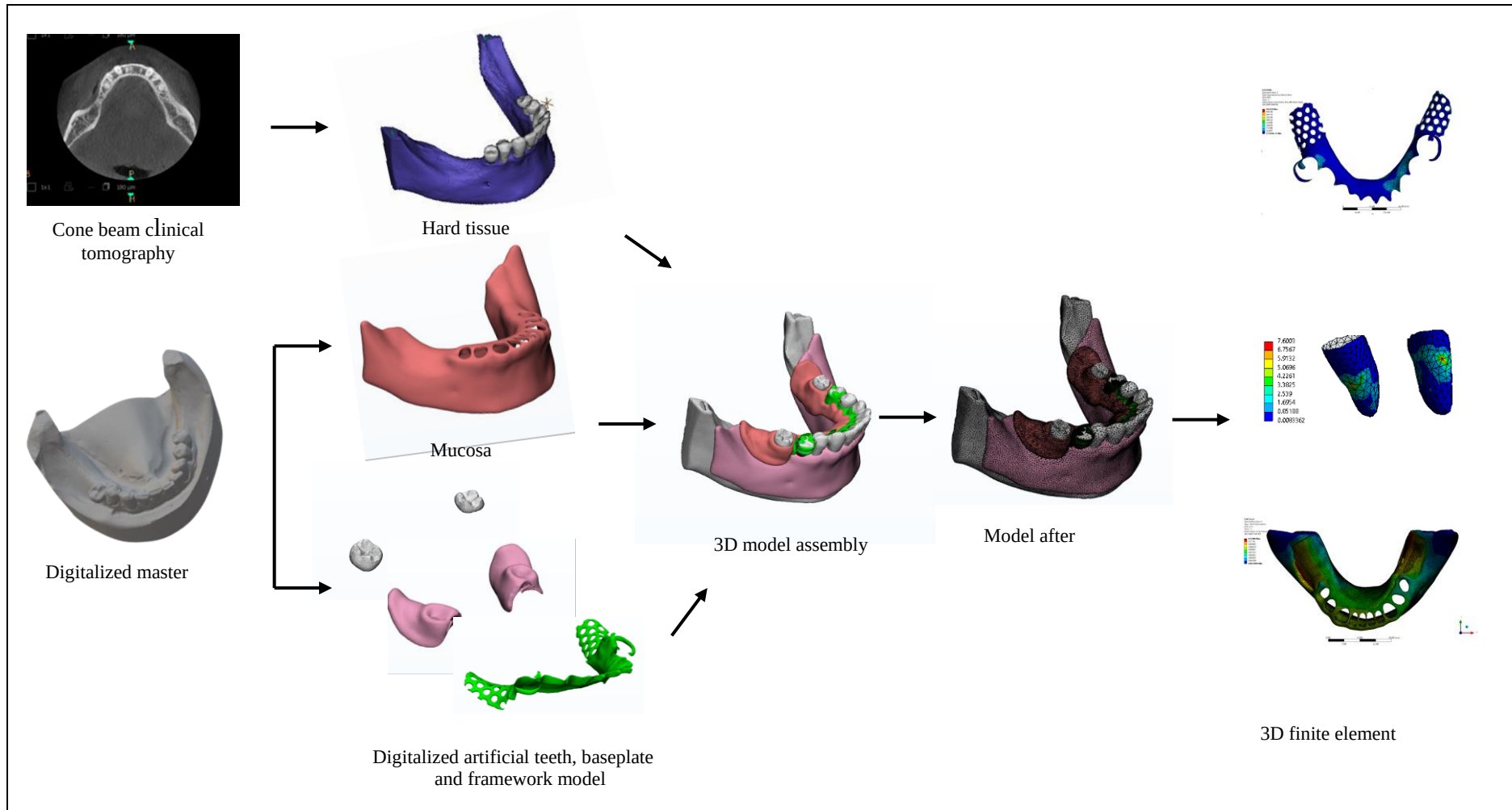


Figure 3.26 Flowchart of Finite Element Analysis Modelling

3.5 Clinical Study

This study is to demonstrate no difference in clinical outcome of the terminal abutment teeth between the investigated PEEK polymer-based framework RPDs and control conventional CoCr metal-based-framework RPDs in replacing posterior teeth in the mandible. Investigation of terminal abutment teeth was conducted using a quantitative approach, and the data were obtained from the clinical and radiographic assessments.

3.5.1 Study Setting

The study was conducted at the Prosthodontics and Periodontics Specialist Clinic, Faculty of Dentistry, Universiti Teknologi MARA (UiTM), Malaysia.

3.5.2 Study Design

This is a prospective, randomized, comparative clinical study conducted on participants with a missing posterior mandibular tooth classified as Kennedy Class I. Participants who voluntarily joined the study were randomly assigned to one of two parallel groups.

- i. Group 1: Participants who were assigned to this group received the tested PEEK polymer-based-framework RPDs
- ii. Group 2: Participants who were assigned to this group received conventional CoCr metal-based-framework RPDs

Ethical approval was obtained from the institutional review board, and all procedures were carried out in accordance with ethical standards and Good Clinical Practice. All participants received verbal and written information and signed informed consent prior to enrolment. Participants were randomized in a 1:1 ratio to receive either a PEEK or a CoCr framework using simple randomization with sequentially numbered, opaque, sealed envelopes (SNOSE). Identical envelopes containing the group assignments were prepared, sealed, and securely stored. After written consent and

baseline recordings, the participant opened the envelope in group order to reveal the allocated treatment regimen.

This was an open-label trial. Participants were not informed of their allocation during the initial planning and impression phases; however, blinding could not be maintained beyond the framework try-in because of the distinct appearance of the two materials

3.5.3 Sample Size Calculation

Based on objectives 3 and 4, the PS Power and Sample Size Calculation software was used to calculate the sample size. With the effect size of 0.25 (err. rob = 0.05, power 1, err. prob = 0.8), and number of groups 2, the minimum effective sample size required was 11 abutment teeth per group (Figure 3.27). Because some participants may contribute more than one terminal abutment tooth, the unit of observation is clustered within patients. Although the initial calculation indicated that 11 abutment teeth per group were sufficient, the recruitment target was increased to 15 abutment teeth per group to compensate for anticipated 20% loss to follow-up.

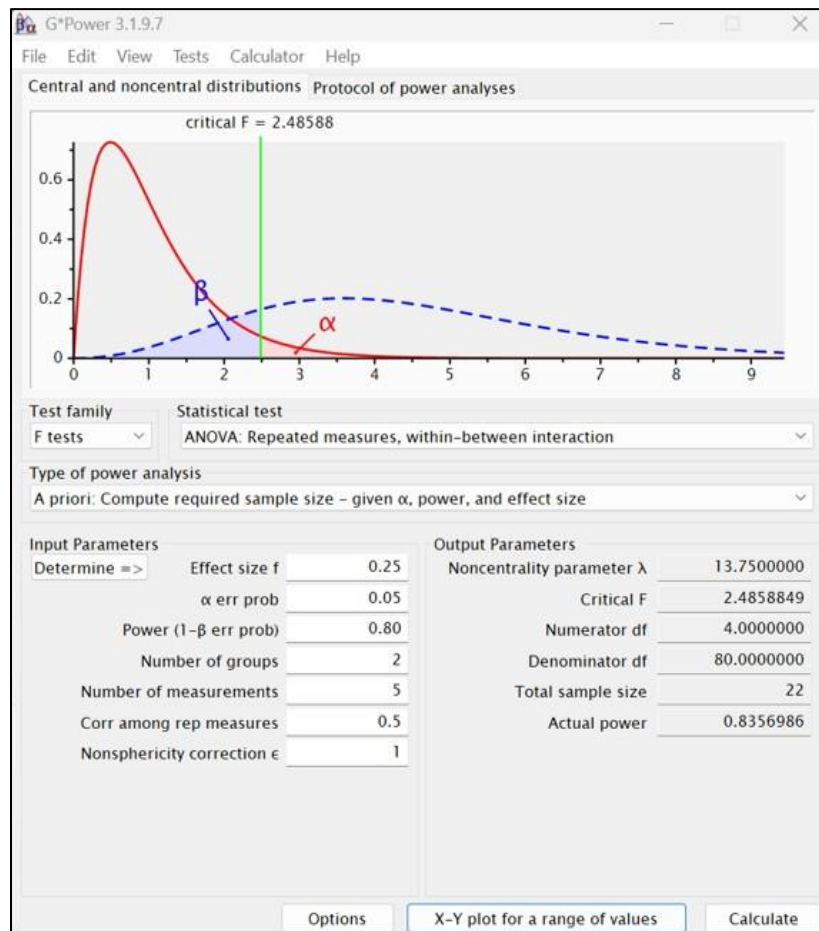


Figure 3.27 Sample Size Calculation Using G*Power Software (version 3.1.9.7). The Analysis was based on a Repeated-measures ANOVA, Between–within Interaction (Two Groups $\times$ Three Time Points), with Medium Effect Size ($f = 0.25$), Significance Level $\alpha = 0.05$, and power = 0.80. The Required Effective Sample Size was 11 Sample Per Group

3.5.4 Patient Selection

A total number of 20 patients (9 PEEK: 11 CoCr) (16 abutment teeth for PEEK: 17 abutment teeth for CoCr) who are 18 years and above, attending the Faculty of Dentistry of UiTM, requesting replacement of posterior teeth was selected. The patient's detailed information and demographics data were recorded and reviewed. The preoperative evaluation including intraoral examination and periapical radiograph of terminal abutment was assessed, accordingly. The inclusion and exclusion criteria are as in Table 3.3.

Table 3.3
Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
1. Participant of either sex and at least 18 years of age with no medical illness or participant with controlled medical illness. 2. Participant with mandibular bilateral free end saddle (Kennedy Classification I) with at least one premolar present. 3. No restriction was placed on the opposing dentition, which included natural dentition, removable partial dentures, and complete dentures. 4. Participant with good oral hygiene (Plaque Score: less than 21%) 5. Ability to understand and provide informed consent before starting the study. 6. Ability and willingness to comply with all study requirements 7. Participant with a clinical condition who can receive the same design of denture (ie presence of at least 7 mm distance from the gingival margin of the mandibular teeth to the functional depth of the alveolar lingual sulcus to allow construction of the lingual plate design) 8. Favourable abutment teeth a) Sound teeth or minimal restoration (involve mesio-occlusal or disto-occlusal only) b) Periodontally healthy: pocket depth < 4mm, with no bleeding on probing or gingival index (GI) 0-1 c) Radiographically, more than 50% of bone support is present between the cementoenamel junction and the root apex.	1. Participant with Kennedy Class I (with any modification), II, III and Class IV 2. Unfavourable abutment teeth a) Caries involving half of the tooth b) Direct restoration involving half of the tooth. c) Tooth with extra coronal restoration d) Endodontically treated tooth e) Periodontally compromised teeth: Pocket depth > 5 mm, bleeding on probing/gingival index more than 1, Grade 2 or Grade 3 mobility f) Radiographically less than 50% of bone support from cementoenamel junction and root apex

3.5.5 Calibration of Examiners

Before the commencement of the clinical study, a calibration process was conducted to ensure the reliability and consistency of the clinical assessments. This process involved both inter-examiner and intra-examiner reliability assessment.

To assess inter-examiner reliability, two examiners were calibrated on three patients, resulting in a total of 10 teeth and approximately 60 periodontal probing sites. Calibration focused on periodontal pocket depth, gingival recession, and tooth mobility. Both examiners independently assessed the same teeth on the same day and were blinded to each other's measurements. Agreement between examiners was evaluated using weighted Kappa statistics for PPD measurements and Cohen's Kappa statistics for categorical variables, including gingival recession and tooth mobility. This calibration process ensured that the student was aligned with the clinical assessment protocols and capable of conducting consistent and reliable evaluations throughout the study.

After calibration, the student served as the sole examiner for the study. Therefore, intra-examiner reliability was assessed to ensure consistency of clinical measurements throughout the study period. To evaluate repeatability, selected patients underwent repeated clinical assessments at different time points during the same visit. For instance, periodontal pocket depth measurements of terminal abutment teeth were recorded before and after the primary impression stage or radiographic examination on the same day.

Intra-examiner agreement for PPD was assessed using weighted kappa statistics, while Cohen's kappa was used for categorical variables, including tooth mobility and gingival recession. Periodic self-monitoring and recalibration sessions were conducted to minimise examiner drift and to maintain adherence to standardised measurement protocols throughout the study.

All statistical analyses were performed using IBM SPSS Statistics version 29.0. Kappa values were interpreted as slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00) agreement.

3.5.6 Clinical Examination

Routine clinical examinations were conducted on both abutment and non-abutment teeth, with detailed records taken for the terminal abutment teeth. Baseline radiograph for terminal abutment teeth was taken. The following variables were assessed for the clinical examination of terminal abutment teeth: clinical soundness, presence or absence of restorations, and the extension and location of restorations,

which were documented according to Black's classification (Figure 3.28 Illustration of G.V Black's Classification of Dental Caries (Figure 3.28, Table 3.4).

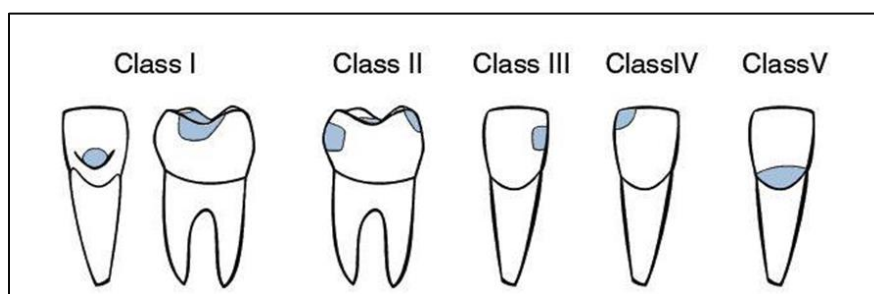


Figure 3.28 Illustration of G.V Black's Classification of Dental Caries

Table 3.4

G.V. Black's Classification of Dental Caries to Record Any Presence of Caries

Caries	Description
Class I	Caries affecting pits and fissures on occlusal third of molars and premolars, occlusal two-third of molars and premolar and lingual part of anterior teeth.
Class II	Caries affecting proximal surfaces of molars and premolars
Class III	Caries affecting proximal surfaces of central incisors, lateral incisors and cuspids without involving the incisal angles
Class IV	Caries affecting proximal including incisal angle of anterior teeth
Class V	Caries affecting gingival one-third of facial or lingual

3.5.7 Periodontal Examination

Periodontal examination of terminal abutment teeth and the following variables was determined: Plaque Index (Silness/Löe 1964), Plaques Score (Ainamo & Bay (1975), Gingival Index (Silness/Loe 1963), Gingival Score (Ainamo & Bay (1975), Probing Pocket Depth (PPD), gingival recession (GR) and tooth mobility (TM) (Akaltan & Kaynak, 2005)

3.5.7.1 Plaque Index

Plaque index (PI) was done according to Silnessb/Löe Index 1964 which measure the state of oral hygiene by based on recording both soft debris and mineralized

deposits on the following teeth: 16, 12, 24,36, 32, 44,36 where the missing teeth will not be substitute (Figure 3.29). Each of the four surfaces of the teeth (buccal, lingual, mesial and distal) is given a score from 0-3 (Table 3.5). The plaque index is calculated by averaging the plaque scores of four surfaces (buccal, lingual/palatal, mesial, and distal) for the selected teeth. The overall plaque index is then determined by averaging the plaque scores of all the selected teeth with score with either excellent, good and poor oral hygiene.

$$\text{Plaque Index for a Tooth} = \frac{\text{Sum of scores for buccal, lingual, mesial, and distal surfaces}}{4}$$

$$\text{Overall Plaque Index} = \frac{\text{Sum of Plaque Index scores for selected teeth}}{\text{Number of selected teeth}}$$

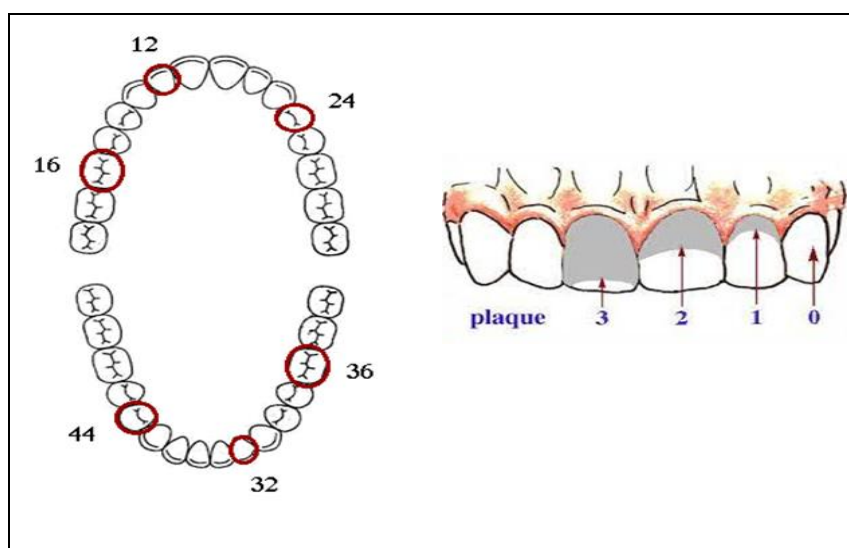


Figure 3.29 a-Specific Teeth Evaluated in the Study, Marked With Red Circles. B- Plaque Index Scoring Diagram.

Courtesy to: <https://capp.mau.se/methods-and-indices/>

Table 3.5

Description of Plaque Index scoring

Score	Description
0	No plaque
1	Thin plaque layer at the gingival margin, only detectable by scraping with a probe
2	Moderate layer of plaque along with the gingival margin but plaque visible to the naked eyes
3	Abundant plaque along the gingival margin, interdental spaces filled with plaque

Table 3.6
Description of Plaque Index Interpretation

Score	Description
0.0-0.9	Excellent oral hygiene
1.0-1.9	Good oral hygiene
2.0-2.9	Fair oral hygiene
Above 3.0	Poor oral hygiene

3.5.7.2 Plaque Score

Plaque scoring, based on Ainamo & Bay (1975), involves assigning dichotomous scores for the presence or absence of plaque on four surfaces of each tooth: mesial, distal, buccal, and palatal or lingual. This method aims to measure plaque accumulation and monitor changes in oral hygiene over time. The presence of supragingival bacterial plaque on each surface is assessed by gently scraping the tooth surface to check for plaque. All teeth are score and each tooth surface is scored as follows: 0: No plaque and 1: Plaque is present along the gingival margin (detectable only by running a probe across the tooth). The description of plaque score interpretation shown in Table 3.7.

$$\text{Plaque score} = \frac{\text{Total number of surfaces with plaque}}{\text{Total number of surfaces examined}} \times 100$$

Table 3.7
Description of Plaque Score Interpretation

Score	Description
Below 20%	This reflects good oral hygiene with minimal plaque accumulation.
20% to 40%.	This indicates some plaque buildup and the need for improved oral hygiene practices.
Above 40%	This suggests significant plaque accumulation, indicating poor oral hygiene and a higher risk of dental issues, such as cavities or gum disease.

3.5.7.3 Gingival Bleeding Index

Gingival Bleeding Index (GI) was be done according to Silness/Löe Index 1963 which record gingival inflammation in three grades in six teeth (16,12,24, 36,32,44) on four surfaces of the teeth (buccal, lingual, mesial and distal). The description of gingival index scoring and interpretation are shown in Table 3.8 and Table 3.9.

Table 3.8
Description of Gingival Index Scoring

Score	Description
0	Normal gingiva; no inflammation; no discoloration (erythema); no bleeding
1	Mild inflammation; slight erythema; no bleeding
2	Moderate inflammation; erythema; bleeding on probing
3	Severe inflammation; severe erythema and swelling; tendency to spontaneous bleeding; possible ulceration

Table 3.9
Description of Gingival Index Interpretation

Score	Description
0.0-0.1	Healthy gingiva
0.1-1.0	Mild inflammation
1.1-2.0	Moderate inflammation
Above 2.1	Severe inflammation

3.5.7.4 Gingival Score

The Gingival Bleeding Score (Ainamo and Bay (1975), is a binary (dichotomous) system where surfaces of teeth are simply recorded as presence or absence of bleeding on probing. Each tooth was evaluated on four surfaces (buccal, lingual/palatal, mesial, and distal), and bleeding was recorded as either present or absent. The description of the gingival score interpretation is shown in Table 3.10.

$$\text{Gingival Bleeding Score (\%)} = \frac{\text{Number of surfaces with bleeding}}{\text{Total number of surfaces examined}} \times 100$$

Table 3.10
Description of Gingival Score Interpretation

Score	Description
Less than 10%	Healthy gingiva with minimal inflammation.
10-20%	Mild gingival inflammation
More than 20%	Significant gingival inflammation, indicating poor gum health.

3.5.7.5 Probing Pocket Depth

Probing pocket depth (PPD) is a clinical measure used to assess the health of the periodontium by determining the depth of the gingival sulcus or periodontal pocket. It is measured from the gingival margin to the base of the pocket using a periodontal probe. The PPD is used to identify signs of periodontal disease, with deeper pockets indicating more advanced disease.

The UNC probe was gently inserted into probable pocket depth the at six sites around each tooth (mesio-buccal, mid-buccal, disto-buccal, mesio-lingual, mid-lingual, and disto-lingual) and the depth recorded in millimetres Figure 3.30. Healthy sites typically exhibit a probing depth of 1-3 mm.



Figure 3.30 Example of Measurement of Probing Pocket Depth (PPD) at terminal Abutment Teeth Using UNC Probe

3.5.7.6 Gingival Recession

Gingival recession (GR) was defined as the apical displacement of the gingival margin from its normal position at the cemento-enamel junction (CEJ), resulting in exposure of the root surface. The presence or absence of gingival recession was first determined at each site. When present, the distance from the CEJ to the gingival margin was measured in millimetres and recorded as a numerical value. Sites with no detectable recession were recorded as 0 mm. Clinical attachment loss (CAL) was calculated as the sum of probing pocket depth and gingival recession at each site.

3.5.7.7 Tooth Mobility

Tooth mobility (TM) was assessed according to Miller's classification (1985), which ranges from 0 to 3, based on the degree of tooth movement. The mobility was measured by applying gentle pressure with two instruments (one on each side of the tooth) in both horizontal and vertical directions. The scoring system is as follows: 0 represents no mobility; 1 indicates mobility of less than 1 mm in the horizontal direction; 2 indicates mobility greater than 1 mm in the horizontal direction; and 3 indicates movement in the vertical (apical) direction.

3.5.8 Oral Health Impact Profile-14 (OHIP-14) Questionnaire

The Oral Health Impact Profile-14 (OHIP-14) questionnaire was used to evaluate patients' oral health-related quality of life (OHRQoL). The OHIP-14 is a validated short form consisting of 14 items across seven domains: functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. Each item was scored on a 5-point Likert scale ranging from 0 ("never") to 4 ("very often"), with higher scores indicating a greater negative impact on OHRQoL.

To ensure comprehension and accurate responses, participants were provided with the OHIP-14 in two language versions: English and Malay. The Malay version used in this study was a previously validated translation (Saub et al., 2005), allowing participants to choose their preferred language when completing the questionnaire.

In this study, the OHIP-14 was administered to all participants at baseline (prior to clinical examination and denture insertion) and again after denture insertion (post-insertion). This time frame was selected to capture the immediate impact of PEEK and CoCr RPDs on patients' comfort, adaptation, and perceived quality of life during the critical early adjustment phase. The mean domain scores and total OHIP-14 scores were calculated for each group (PEEK and CoCr), and comparisons were made between pre- and post-insertion values to assess changes in OHRQoL associated with each framework material.

3.5.9 Clinical Procedure

The primary impression was obtained using alginate (Kromopan, Lascod, Italy) to create a study model, which was then used for the construction of the secondary impression tray. Tooth modification for both PEEK and CoCr frameworks was performed following conventional CoCr design principles prior to the secondary impression. A secondary impression was taken using medium bodies monophase polyvinyl siloxane (PVS) material (Aquasil Ultra, Dentsply Sirona). Subsequently, a master cast was constructed based on the secondary impression and sent for the fabrication of either the CoCr or PEEK RPD depending on the study group allocation.

All treatment procedures including the primary impression, RPD design, secondary impression, framework try-in, teeth try-in, and denture insertion were performed by a single postgraduate student at the dental specialist clinic. The fabrication of the dentures was outsourced to Ocean Dental Laboratory, where a single technician managed the entire process. All denture designs were approved by the researcher prior to the manufacturing process.

The RPD design for both cases were standardized to ensure consistency and enabled a reliable comparison between the two groups in the study. Each design featured a lingual plate as the major connector, with rest seats placed on the mesial surfaces of the terminal abutment teeth. Aker clasps were used as direct retainers for both cases. The detail dimension of CoCr RPD and PEEK RPD design is presented in Table 3.11.

For the CoCr frameworks, the Aker clasps utilized a 0.25 mm undercut, following conventional design principles. In contrast, for the PEEK frameworks, a 0.5 mm undercut was employed, in accordance with the manufacturer's instructions and

supported by previous studies (Dakhli et al., 2023; Juvora Ltd., 2022). The rest seats followed the conventional CoCr design, triangular or spoon-shaped, approximately 2.0 mm wide buccolingually, 1.5 mm long mesiodistally, and 1.5 mm deep. For the lingual plate design, the framework extended vertically to cover the lingual surfaces of the anterior teeth, with a uniform thickness of 1.2–1.3 mm.

The framework try-in stage is conducted to ensure proper adaptation and fit of the frameworks to the supporting tissues and abutment teeth. Any discrepancies in the fit were adjusted to ensure optimal contact with the rest seats, stability of the major connector, and passive engagement of the clasps. Following that, teeth try-in stage was performed to evaluate the occlusal relationship, aesthetics, and phonetics. This step allowed for verification of the planned tooth arrangement and offered an opportunity to make necessary adjustments in response to patient feedback or clinical findings.

Following the successful framework and teeth try-in, denture delivery was conducted. During this phase, the final prostheses were evaluated intraorally for fit, retention, stability, and occlusion. The occlusal contacts were checked to eliminate any high spots, ensuring even distribution of occlusal forces. Patients were provided with verbal instructions on denture maintenance and proper use following denture delivery. Follow-up appointments were scheduled to monitor the patient's adaptation and to address any post-delivery concerns. The flow of the clinical steps is illustrated in Figure 3.31. Figure 3-32 show the side-by-side comparison of completed PEEK and CoCr denture.

Table 3.11
Material and Dimension of CoCr RPD and PEEK RPD

Dimension	CoCr	PEEK
Material	Weronit (Bego)	BioHPP, Bredent)
Major connector	Thickness: around 0.5-0.65 mm Width: it covers the entire anterior lingual surface	Thickness: around 1.2-1.3 mm Width: it covers the entire anterior lingual surface
Clasps	Undercut: 0.25 mm Thickness: 1.0 mm, tapering to approximately 0.6 mm at the retentive tip. Width: The width at the thickest part is typically around 2.0 mm, tapering to approximately 1.2 mm at the retentive tip.	Undercut: 0.5 mm Thickness: 1.5 mm at the thickest part, tapering towards the tip (1.3 mm) Width: Widths around 2.0 mm or 2.5 mm
Rest	Following conventional design, approximately 2.0 mm wide buccolingually, 1.5 mm long mesiodistally, and 1.5 mm deep	

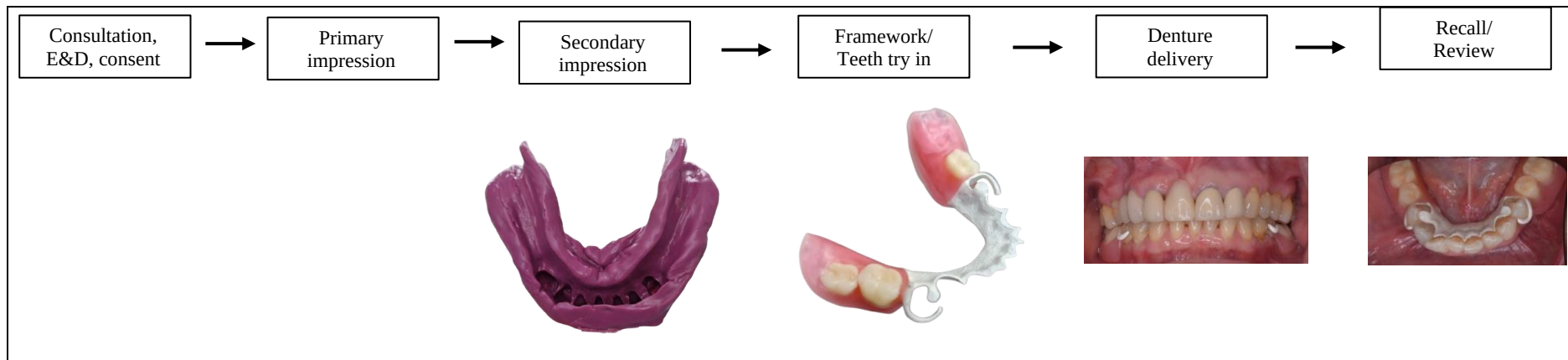


Figure 3.31 Step of Clinical Procedures



Figure 3.32 Side by Side Comparison of PEEK Denture and CoCr Denture

3.5.10 Post-treatment Maintenance Review

Following denture delivery, the patient was called for a review one week, four weeks and six months later. Routine clinical and periodontal examination, oral prophylaxis, and oral hygiene instructions were performed during the recall appointment based on patient need. A radiographic examination (periapical radiograph) of the abutment teeth was taken as baseline data. If the patient experiences any dental and periodontal problems, including tissue irritation from their prostheses, they were advised to schedule an appointment, and necessary treatment was be provided. The prosthesis will be removed if any excessive mobility of an abutment tooth (TM >1) without the presence of plaque is found, and appropriate investigation and treatment will be provided.

3.5.11 Evaluation of Prognosis of the Abutment Teeth

Prognosis of the abutment teeth were evaluated based on Table 3.12. Deepest probing depth of six probing sites on an abutment was used to determine the pocket depth.

Table 3.12

Description Prognosis of the Abutment Teeth After Six-Months

Prognosis	Description
Good	a) Clinical: No new caries detected b) Periodontal: no pocket depth more than 4 mm, no mobility detected
Guarded	a) Clinical: Caries involving enamel or dentin only, dislodge restoration but teeth are restorable b) Periodontal: pocket depth 4-mm, mobility Grade 1 detected
Poor	a) Clinical: Caries is extending to pulp that required endodontic therapy, unrestorable abutment teeth b) Periodontal: pocket depth more than 6 mm, more than Grade 1 mobility

3.5.12 Data Analysis

Collected data were tabulated in a Microsoft Excel spreadsheet (Microsoft Inc., Redmond, WA) and subsequently exported to the Statistical Package for the Social

Sciences (SPSS Version 29.0, IBM, Chicago, USA) for analysis. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were generated to summarize the characteristics of the study sample.

Inferential statistical tests were selected based on the variable type and study design. The occurrence of new dental caries, restoration dislodgement and tooth mobility, that required clinical intervention was analysed using the Cochran Q test to evaluate changes over time. For continuous periodontal outcomes, within-group comparisons across the three time points were performed using Repeated Measures Analysis of Variance for each framework material. Between-group differences at each follow-up interval were assessed using mean differences with corresponding ninety-five percent confidence intervals. Patient-reported OHQoL was analysed using a paired t-test for within-group changes and an independent t-test for comparisons between the two framework groups. A significance level of $p < 0.05$ was used for all statistical tests.

For participants who missed scheduled follow-up visits, only the data from attended time points were included in the analysis. No statistical imputation was performed for missing values. This strategy ensured that all available data were utilized while maintaining consistency in longitudinal comparisons. The flow of the clinical study is illustrated in Figure 3.33.

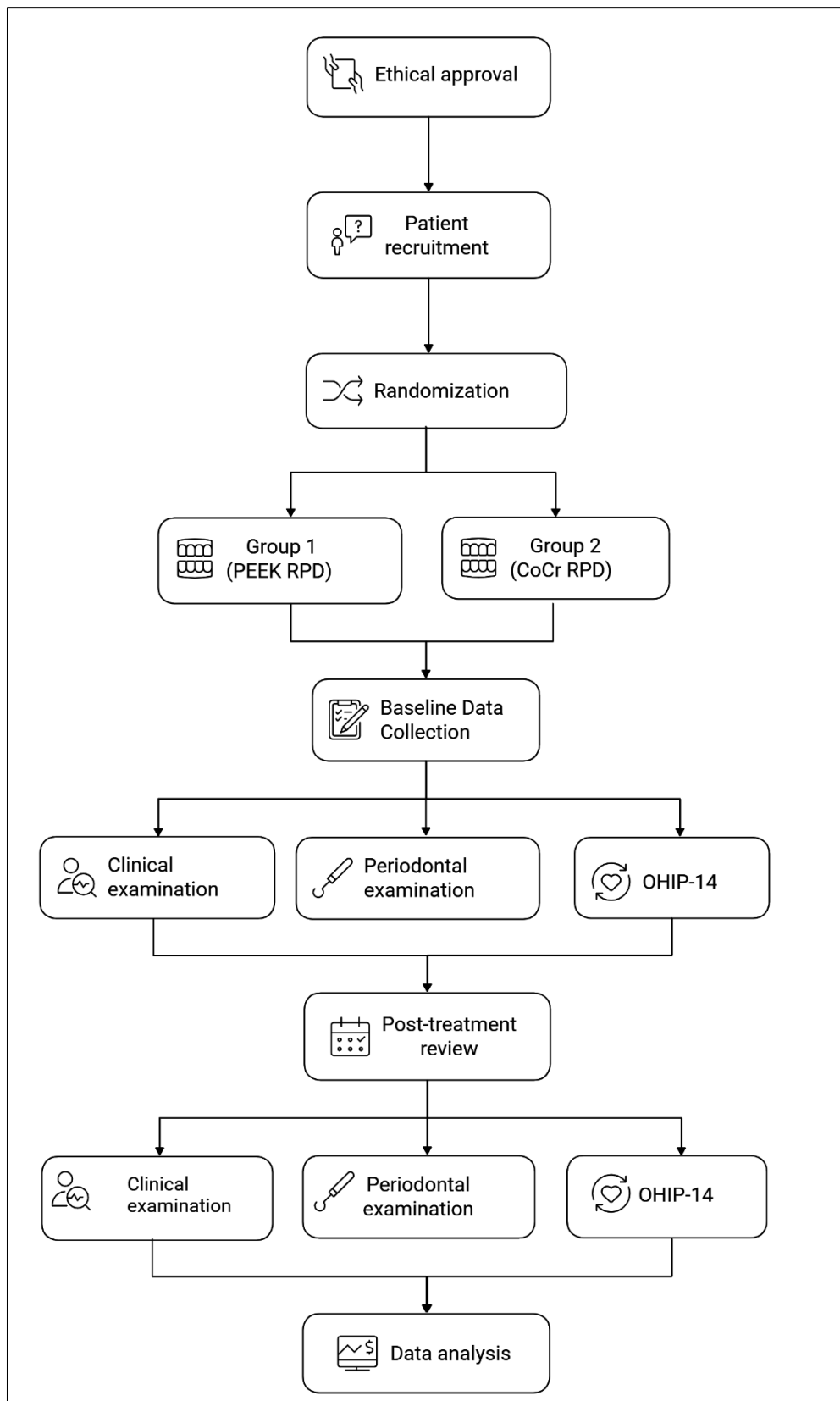


Figure 3.33 Flowchart of Clinical Study

CHAPTER 4

RESULTS

4.1 Introduction

In this chapter, the study results are presented in two parts: a finite element analysis study and a clinical study conducted to evaluate the biomechanical and clinical performance of RPD fabricated from two different materials, PEEK and CoCr.

The FEA was conducted to assess and compare the deformation and stress distribution in the framework, PDL, and mucosa under different framework materials (CoCr and PEEK), major connector designs (bar and plate), and rest position. The results are reported in terms of deformation and Von Mises Stress (VMS) for each component.

The clinical component assessed the short-term clinical outcomes of RPDs fabricated from PEEK and CoCr frameworks. Patients were recalled for review at one week (for initial denture adjustment), followed by evaluations at one month and six months to assess clinical and periodontal parameters of the terminal abutment teeth. OHIP-14 was administered at baseline and post-operative insertion to assess the immediate impact of PEEK and CoCr RPDs on patients' comfort, adaptation, and perceived quality of life, which is critical following the denture insertion.

For the clinical study, descriptive statistical analysis was performed to assess normality, using the Shapiro-Wilk test. A p-value > 0.05 was considered to indicate that the normality assumption was met.

4.2 Convergence Test Prior to Finite Element Analysis Study

Prior to the final analysis, a mesh convergence test was conducted on the PEEK plate framework to determine the optimal mesh density for FEA. This test is essential to ensure that the simulation results are accurate and independent of mesh size. Three configurations: coarse (182,718 elements), medium (388,519 elements), and fine (727,948 elements) were evaluated. The objective was to identify the point at which further mesh refinement no longer yielded significant changes in deformation or stress.

The maximum VMS recorded increased from 255.4 MPa in the coarse mesh to 289.9 MPa in the medium mesh, and to 293.9 MPa in the fine mesh. Since the difference between the medium and fine meshes was only 1.4%, the medium mesh was selected for all subsequent simulations to balance accuracy and computational efficiency (Table 4.1).

Table 4.1
Mesh Convergence Test Results for PEEK Plate Framework: Effect of Mesh Density on Maximum Von Mises Stress

Mesh density	Number of elements	Max Von Mises Stress (MPa)	Percentage difference from previous
Coarse	182718	255.4	—
Medium	388519	289.9	+13.5%
Fine	727948	293.9	+1.4%

4.3 Finite Element Analysis Study

A vertical occlusal load of 120 N was applied to the denture teeth, simulating functional masticatory contacts. This force was equally distributed bilaterally to mimic symmetrical biting during normal function. The occlusal load was transmitted through the denture framework and distributed to the terminal abutment teeth via the PDL and to the edentulous ridge mucosa through the denture base.

The descriptive and comparative analyses were conducted to evaluate the effect of framework material, major connector design, and rest position on deformation and stress distribution within the framework material, PDL, and mucosa (Figure 4.1). Deformation (in millimetres) and Von Mises Stress (in megapascals) were assessed using FEA in all framework configurations. Deformation is defined as the displacement of a structure or a change in shape/size, movement when a force is applied, while Von Mises Stress is defined as a calculated value used to predict when a material will yield or fail. Figure 4.1 illustrates four design-material combinations served as the comparison groups in the study.

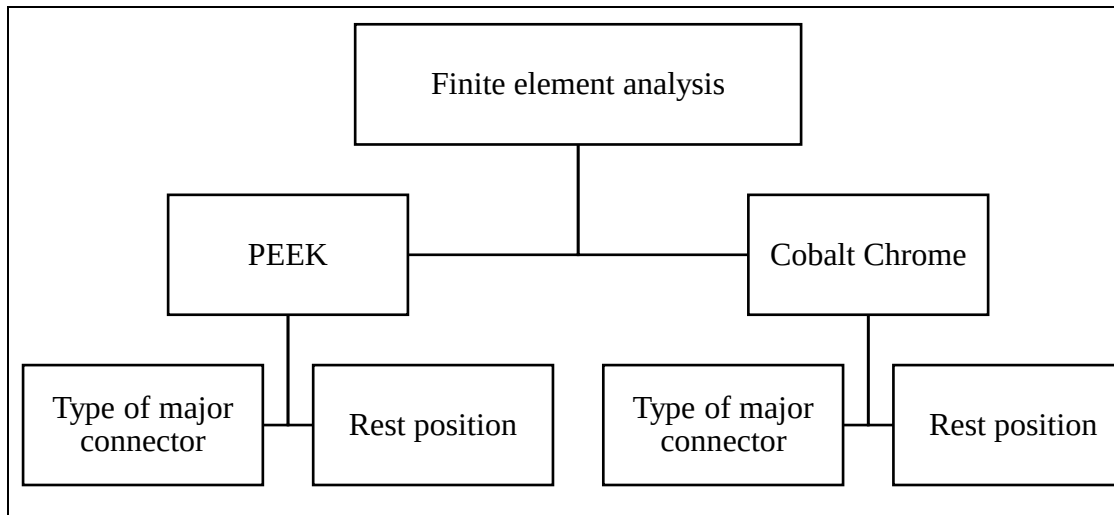


Figure 4.1 Analysis of the Framework Configurations Using Finite Element Analysis: Comparison Groups Based on Material (PEEK and Cocr) Connector Type (Bar and Plate) and Rest Position (Mesial and Distal)

4.3.1 Influence of Major Connector Design on Biomechanical Behaviour (Material Constant)

When the framework material was kept constant, the choice of major connector design significantly influenced the overall mechanical performance and biomechanical response. This section shows how different major connector designs affect stress distribution and deformation patterns, using either PEEK or CoCr framework material.

4.3.1.1 Poly-ether-ether-ketone (PEEK): Plate Versus Bar

In terms of deformation, PEEK bar design demonstrated lower deformation in the framework and mucosa, but 25% higher deformation in the PDL (Table 4.2). In terms of Von Mises Stress, PEEK bar design greatly reduces mucosa stress up to 84%, but PDL stress increased to 58% together with an increase in framework stress of about 24%, indicating risk of deformation unless reinforced (Table 4.3). Figure 4.2 shows the stress distribution map of the PEEK framework, PDL, and mucosa. Clinically, these findings suggest that while PEEK bar designs offer superior stress relief to the mucosa, they may also enhance patient comfort. However, the increased stress and deformation observed in the framework and PDL highlight the need for design optimization to maintain abutment tooth integrity and ensure long-term clinical performance.

Table 4.2

Percentage Differences in Deformation Between Plate and Bar Design in PEEK Framework

Component	Deformation (mm)		% difference
	PEEK plate	PEEK bar	
Framework	0.786	0.158	80% lower for bar
PDL	0.009	0.012	25% higher for bar
Mucosa	0.537	0.165	69% lower for bar

Table 4.3

Percentage Differences in Von Mises Stress (MPa) between Plate and Bar Design in PEEK Framework

Component	Von Mises Stress (MPa)		% difference
	PEEK plate	PEEK bar	
Framework	504.2	664.2	24% higher for bar
PDL	0.802	1.913	58% higher for bar
Mucosa	0.441	0.072	84% lower for bar

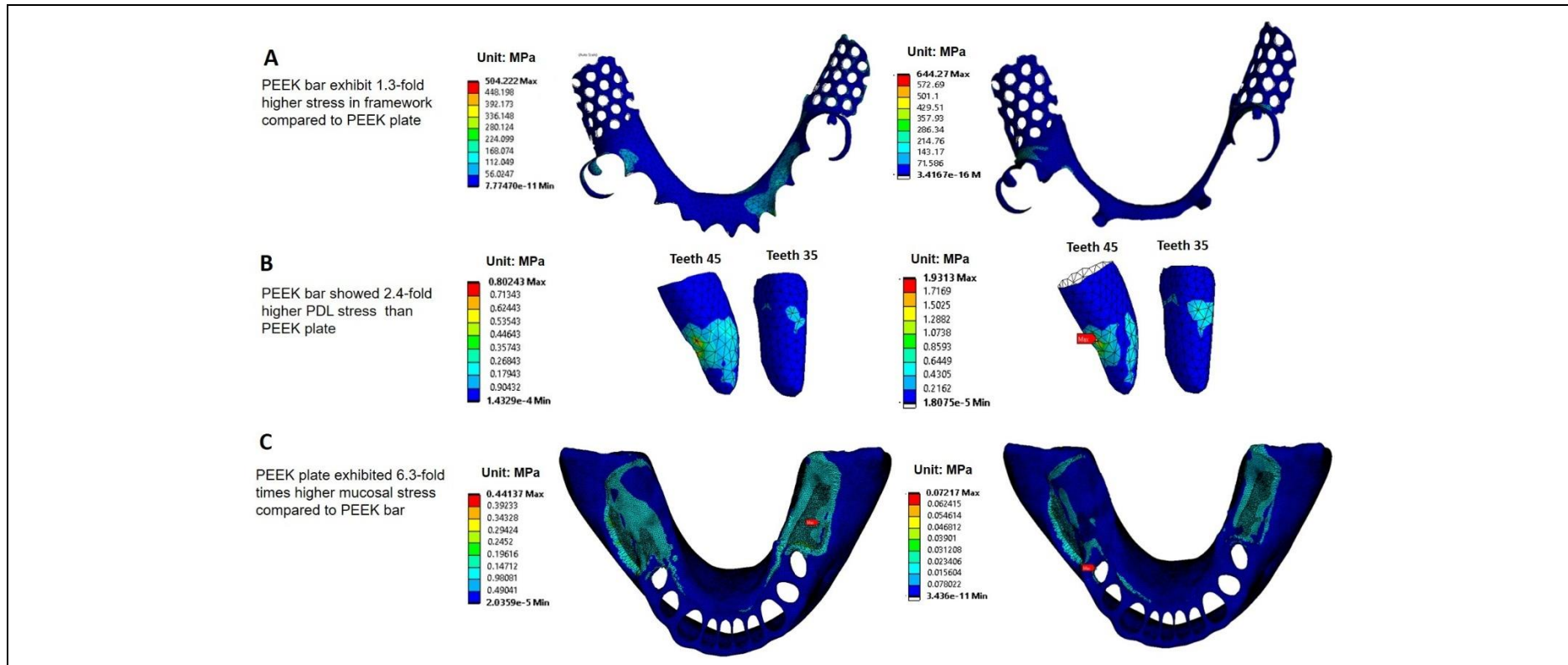


Figure 4.2 Scales Indicate Stress Distribution Pattern in PEEK (Loading level: 120 N; Red Color Indicates the Region with the Greatest Equivalent Stress).

A. Framework: Bar design exhibited 1.3-fold higher stress, particularly along the major connector and clasp junctions. Periodontal ligament (PDL): Stress was concentrated in the mid-root of abutment teeth, with greater stress observed in bar design, indicating greater load transfer through the occlusal rest and guiding plane C. Mucosa: The PEEK plate design showed higher stress beneath the distal extension base, which suggests that the plate design directs a larger portion of the load toward the mucosal support

4.3.1.2 Cobalt- Chromium (CoCr): Plate Versus Bar

In term of deformation, the CoCr plate design show higher deformation in framework and mucosa, but 9% lower in PDL deformation (Table 4.4). The CoCr bar design demonstrated a lower Von Mises Stress across all evaluated structures: framework, PDL, and mucosa, when compared to the CoCr plate design, indicating improved stress distribution with the bar configuration (Table 4.5). Stress within the mucosa was mainly concentrated at the free-end saddle region, with markedly lower values observed for the bar design. Clinically, CoCr bar design provides more favorable load transmission and stress distribution, potentially minimizing mucosa pressure and enhancing denture support. The reduced stress in the framework, PDL, and mucosa indicates that the bar configuration may contribute to improved comfort, abutment tooth preservation, and long-term prosthesis stability compared to the plate design. Figure 4.3 show stress distribution map of CoCr framework, PDL and mucosa.

Table 4.4

Percentage Differences in Deformation Between Plate and Bar Design in Framework

Component	Deformation (mm)		% difference
	CoCr plate	CoCr bar	
Framework	0.276	0.135	51% lower for bar
PDL	0.010	0.011	9% lower for plate
Mucosa	0.186	0.140	24% lower for bar

Table 4.5

Percentage Differences in Von Mises Stress (MPa) between Plate and Bar Design in CoCr Framework

Component	Von Mises Stress (MPa)		% difference
	CoCr plate	CoCr bar	
Framework	353.5	197.9	44% lower in bar
PDL	2.207	1.709	23% lower in bar
Mucosa	0.157	0.057	57% lower in bar

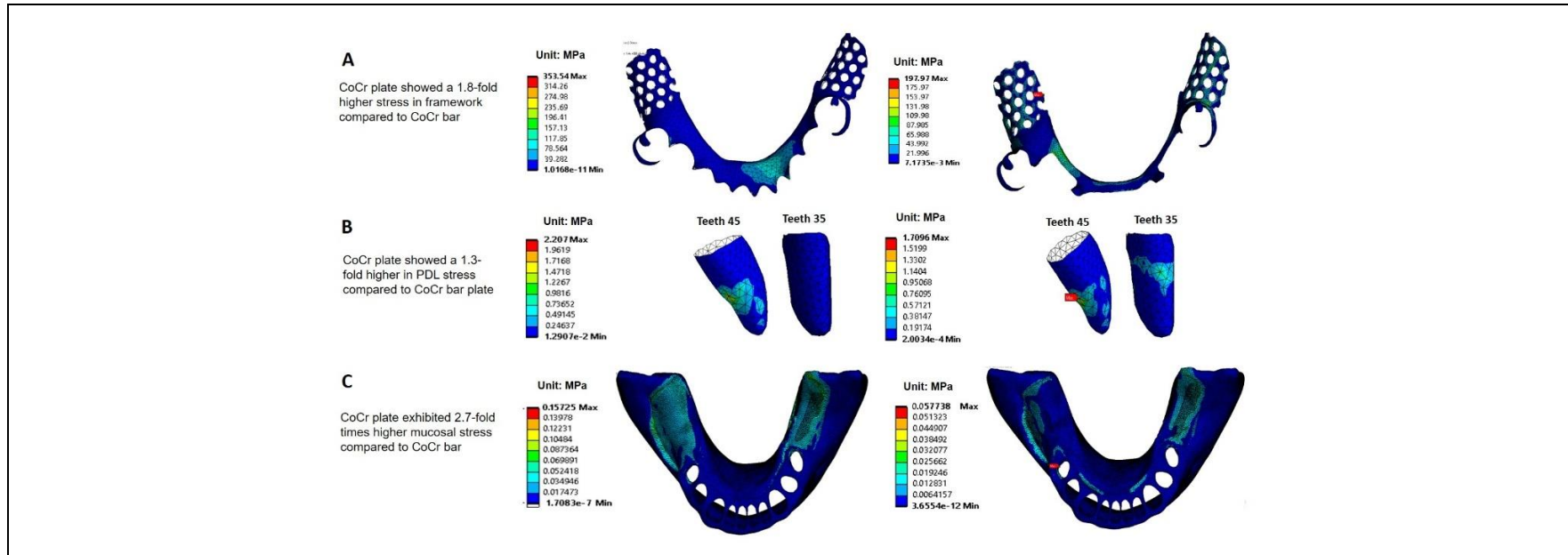


Figure 4.3 Stress Distribution Pattern in CoCr (Loading level: 120 N; Red Color Indicates the Region with the Greatest Equivalent Stress), with All Stresses Being Lower in the Bar Design.

A. Framework: CoCr framework demonstrates concentration of stresses along the major connector, around the mesh retention area, and at the clasp shoulders on both sides. B. Periodontal ligament (PDL): Stress distribution in the PDL of the terminal abutment teeth (teeth 35 and 45) shows localized stress concentration at the mid-root area, suggesting that bending moments are transmitted from the framework through the rest seats and proximal plates to the abutment roots in both design C. Mucosa: Stress was mainly distributed along the alveolar crest beneath the distal extension base, with the posterior mucosa showed the highest stress, reflecting functional load transmission through the denture base, with secondary support provided by the abutment teeth via the framework components

4.3.2 Influence of Rest Position on Biomechanical Behaviour (Connector Design Constant)

The placement of rests plays a critical role in directing occlusal forces and stabilizing the denture base, particularly in distal extension cases. To investigate how the location of occlusal rests influences the biomechanical response of the prosthesis and supporting structures, the major connector design was kept constant while varying the rest position between the mesial and distal rest positions. By standardizing the connector type, any observed differences in stress distribution and deformation patterns could be attributed specifically to the rest configuration, thereby providing insight into optimal rest positioning to improve abutment and tissue support.

4.3.2.1 Lingual Plate: Mesial Versus Distal Rest

For the PEEK framework, the distal rest design exhibited greater deformations and stress, whereas the mesial rest design demonstrated 66 % lower deformation and 43% lower stress, indicating greater flexibility and load transfer toward the distal extension. Within the PDL, the distal rest design exhibited markedly lower deformation and stress (approximately 89% lower), suggesting predominant mesial loading. The mucosa showed higher deformation and stress in the distal rest design, reflecting greater displacement along the distal extension and indicating a tendency for displacement and stress distribution in that direction (Table 4.6, Figure 4.4). Therefore, clinically for PEEK plate, a mesial rest is recommended when prosthesis stability and patient comfort is prioritized, whereas a distal rest should be considered when the main goal is to protect the abutment tooth and its PDL.

For the CoCr framework, a similar trend was observed, with the distal rest design showing higher deformation consistent with the rigid framework transmitting more movement to the distal extension. In the PDL, both deformation and stress were predominantly observed in the mesial rest design, indicating greater mesial stress concentration. The mucosa experienced greater deformation with the distal rest design, but stress was mainly concentrated mesially, consistent with the stiffer nature of the CoCr framework (Figure 4.5, Table 4.6). Clinically, in CoCr plate designs, a distal rest is preferred to reduce stress and deformation in both the PDL and mucosa, supporting abutment preservation and biomechanical balance.

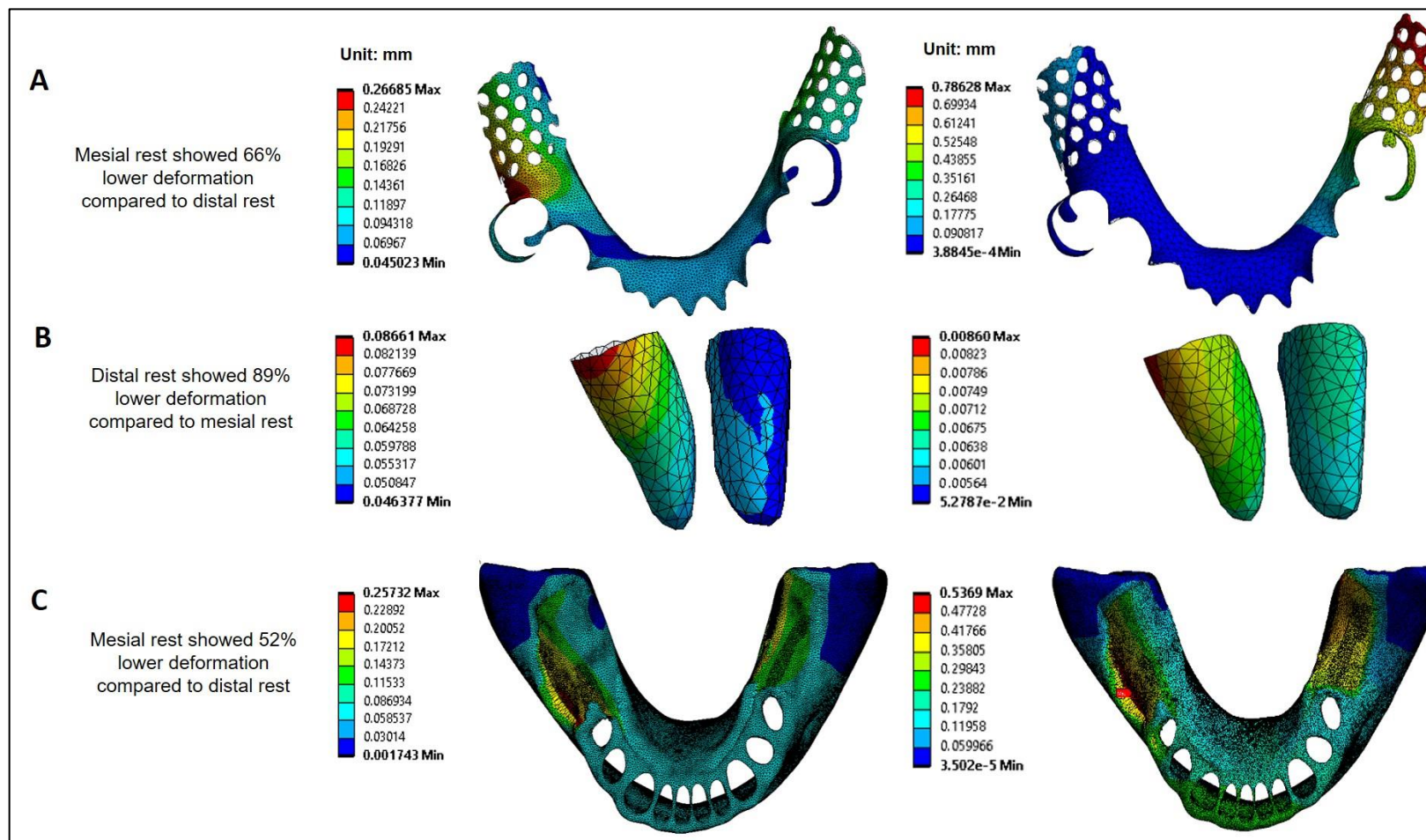


Figure 4.4 Comparative Deformation Pattern of Framework, PDL, and Mucosa in PEEK Plate with Mesial and Distal Rest Designs

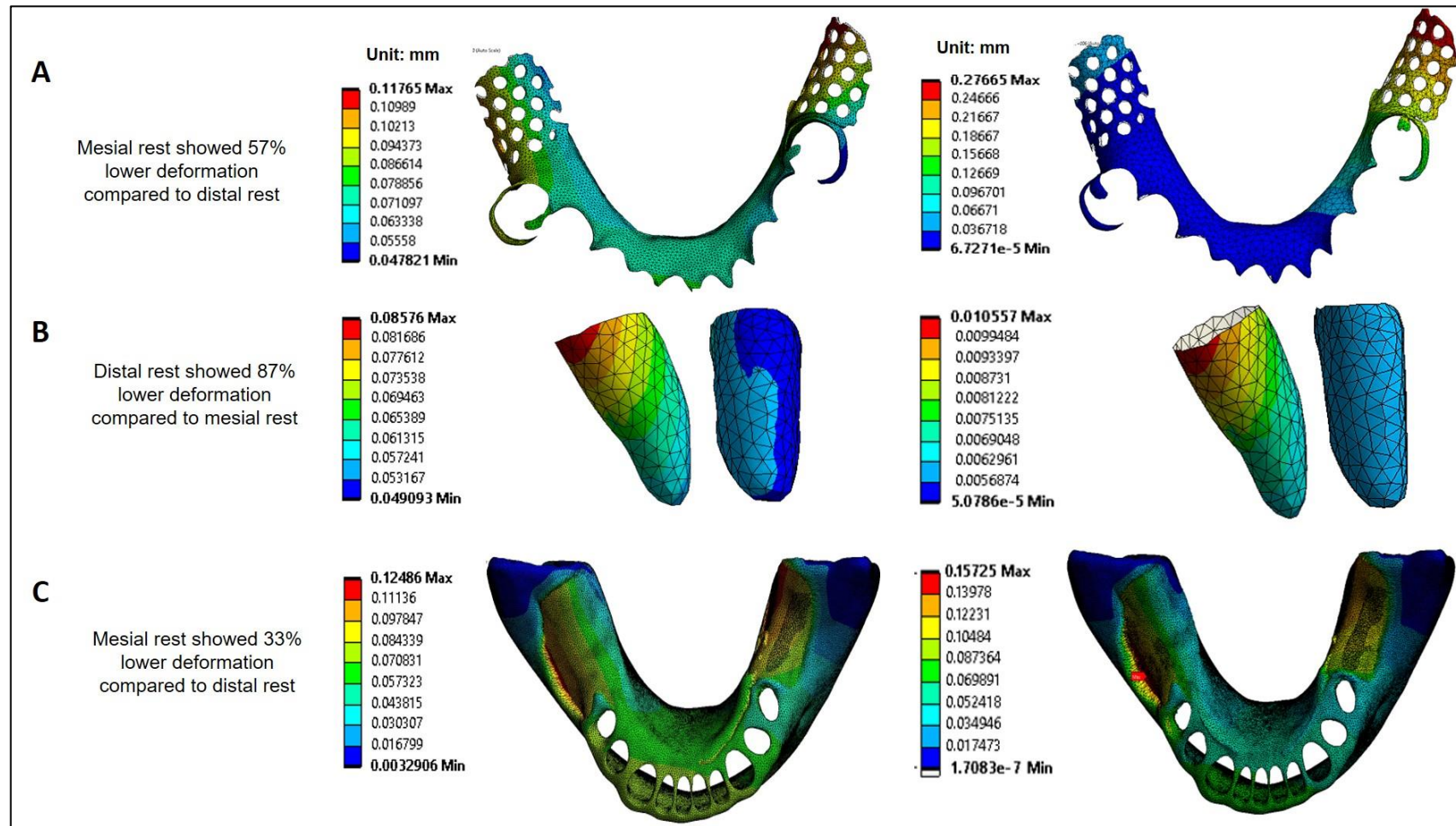


Figure 4.5 Comparative Deformation Pattern of Framework, PDL, and Mucosa in CoCr Plate with Mesial and Distal Rest

Table 4.6

Percentage Difference in Von Mises Stress (MPa) between Mesial and Distal Rest Positions in Plate Design for Two Materials

Component	Von Mises Stress (MPa)					
	PEEK plate		% difference	CoCr plate		% difference
	Mesial	Distal		Mesial	Distal	
Framework	286.6	504.2	43% lower in mesial	778.7	353.6	54 % lower in distal
PDL	7.603	0.802	89% lower in distal	9.049	2.207	76 % lower in distal
Mucosa	0.692	0.441	36% lower in distal	0.359	0.157	56 % lower in distal

4.3.2.2 Lingual BAR: Mesial Versus Distal Rest

For PEEK, the mesial rest showed lower deformation in the framework and mucosa, accompanied by a 6% reduction in framework stress and a 51% reduction in mucosal stress compared to the distal rest. Conversely, the distal rest resulted in lower PDL deformation (67% lower) and stress (49% lower) (Table 4.7, Figure 4.6).

For CoCr, mixed findings were observed. The mesial rest exhibited lower framework and PDL deformation, along with reduced framework stress (145.1 MPa) and lower PDL stress (0.915 MPa). In contrast, the distal rest reduced mucosal deformation by 39% and stress by 19%. (Table 4.7, Figure 4.7).

Clinically, a mesial rest is preferable when prioritizing prosthesis stability and mucosal comfort, while a distal rest is better for protecting the abutment tooth and its PDL for PEEK bar. However, for CoCr bar, rest position should be chosen based on treatment priorities: a mesial rest better protects the abutment tooth and PDL, while a distal rest favours mucosal preservation and overall prosthesis stability.

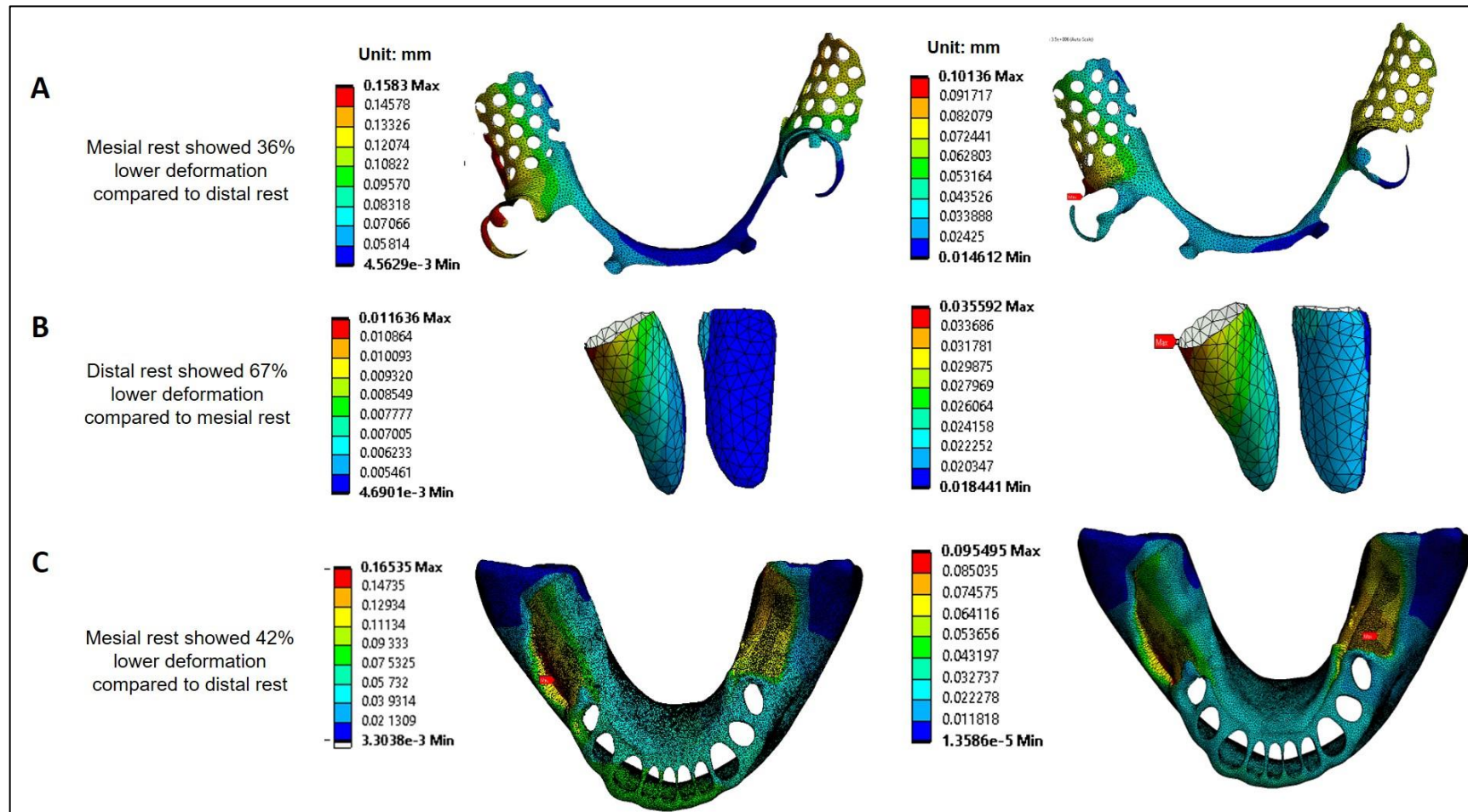


Figure 4.6 Comparative Deformation Pattern of Framework, PDL, and Mucosa in PEEK Bar with Mesial and Distal Rest Designs

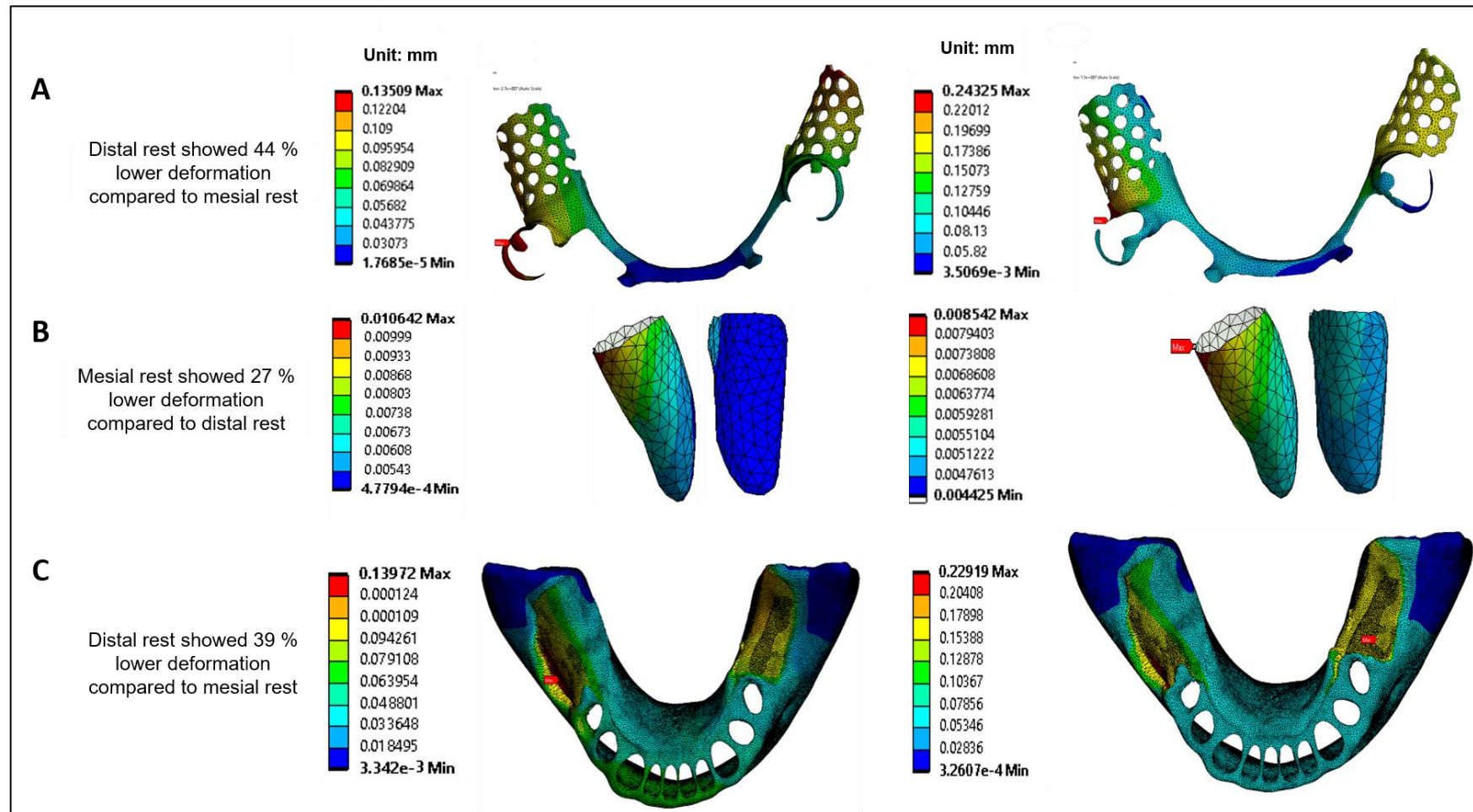


Figure 4.7 Comparative Deformation Pattern of Framework, PDL, and Mucosa in CoCr bar with Mesial and Distal Rest Designs

Table 4.7

Percentage Difference in Von Mises Stress (MPa) between Mesial and Distal Rest Positions in Bar Design for two Materials

Component	Von Mises Stress (MPa)					
	PEEK bar		% difference	CoCr bar		% difference
	Mesial	Distal		Mesial	Distal	
Framework	604.6	644.3	6 % lower in mesial	145.1	197.8	27 % lower in mesial
PDL	3.815	1.931	49 % lower in distal	0.915	1.709	46 % lower in mesial
Mucosa	0.035	0.072	51% lower in mesial	0.072	0.058	19 % lower in distal

4.3.3 Summary of Design Recommendation based from FEA Study

The mechanical performance of RPD frameworks is strongly influenced by the inherent properties of the materials used. In this study, the comparison between PEEK and CoCr highlights how material stiffness, flexibility, and load distribution affect deformation and stress behaviour across the prosthesis and supporting structures.

For material-specific design, in the case of CoCr, the bar design demonstrated superior biomechanical performance, with lower stress observed in all components. Thus, it can be recommended for Kennedy Class I cases with good to moderate periodontal support, as they transmit less stress to the PDL and direct more load to the mucosa. For the plate design, CoCr plates are only recommended for patients with strong abutments, as stress is primarily concentrated on the abutment teeth.

In the case of PEEK, it can be an alternative for a metal-allergic patient. The bar design is gentler on the PDL and mucosa compared to the plate design, but it experienced higher stress within the framework itself, potentially compromising long-term support and splinting effect. Therefore, it may be more suitable for short-span cases and patients with low occlusal forces. If it is intended to be used for Kennedy Class I cases, reinforcement of the bar design may be necessary. PEEK plates may not be ideal for Kennedy Class I cases due to their flexibility and potential for long-term deformation. However, it may be considered in patients with metal sensitivity, compromised periodontal support, and good residual ridge anatomy, as stress is more evenly distributed between the PDL and mucosa.

In terms of rest position, for PEEK frameworks, the mesial rest benefits both the framework and the mucosa by minimizing structural deformation and soft tissue displacement across both plate and bar designs. Its lower deformation and internal stress enhance the stability of the denture base and mucosal comfort. Therefore, if framework stability and tissue comfort are prioritized, the mesial rest design is preferred. However, the distal rest provides better protection for the abutment tooth, making it more suitable when biological preservation is the main concern. The distal rest benefits the PDL by reducing stress concentration on the abutment support. Hence, if the primary goal is to protect the abutment tooth, the distal rest design may be slightly more favourable.

For the CoCr plate design, distal rest placement is more favourable as it consistently reduces stress and deformation in both the PDL and mucosal tissues, thereby promoting better biomechanical balance and enhancing abutment preservation. For the CoCr bar design, the mesial rest is recommended when the goal is to protect the abutment tooth (PDL) and minimize internal stress within the framework. Conversely, if denture base stability, soft tissue preservation, tissue adaptation, and overall prosthesis comfort are the primary considerations, the distal rest may be a slightly better option, as it demonstrates lower deformation and stress compared with the mesial rest. Overall, the rest position should be selected based on individual patient factors, balancing the need for prosthesis stability with the protection of supporting structures.

4.4 Calibration of Examiners for Clinical Study

Inter-examiner agreement was assessed using weighted kappa statistics for PPD measurements and Cohen's kappa for categorical clinical parameters. Substantial agreement was observed for periodontal pocket depth at all measured sites, including distobuccal ($\kappa = 0.677$, 95% CI: 0.481 to 0.873, $p = 0.002$), mid-buccal ($\kappa = 0.808$, 95% CI: 0.551 to 1.064, $p = 0.002$), and distolingual ($\kappa = 0.783$, 95% CI: 0.388 to 1.177, $p = 0.011$). For categorical assessments, Cohen's kappa demonstrated moderate agreement for tooth mobility ($\kappa = 0.545$, $p = 0.053$) and almost perfect agreement for gingival recession ($\kappa = 1.000$, $p = 0.002$).

Intra-examiner agreement for PPD measurements was generally high. Weighted kappa values indicated substantial to almost perfect agreement across most sites, including distobuccal ($\kappa = 0.737$), mid-buccal ($\kappa = 0.800$), distolingual ($\kappa = 1.000$), mid-lingual ($\kappa = 0.800$), and mesiolingual surfaces ($\kappa = 0.783$), with statistically significant

p-values. Cohen's kappa demonstrated almost perfect intra-examiner agreement for both tooth mobility and gingival recession ($\kappa = 1.000$, $p = 0.002$).

4.5 Clinical Study

4.5.1 Socio-demographic Characteristics

Initially, 97 individuals were screened for eligibility. Of these, 74 did not meet the inclusion criteria, and three declined to participate. The remaining 20 participants (11 women, 9 men) were randomized into two groups: 11 participants in the control group (CoCr) and 9 participants in the experimental group (PEEK). A total of 18 abutment teeth were recorded in the control group and 16 in the experimental group. This difference reflects variation in clinical presentation, as participants could contribute either one or two premolar abutment teeth. Two participants did not proceed with denture insertion and were excluded, leaving 18 patients who completed denture insertion, baseline assessments, and the one-week review. At the 1-month and 6-month follow-ups, 17 patients remained, as one patient was unable to continue due to surgery.

The CONSORT flow diagram in Figure 4.8 illustrates the number of participants at each follow-up stage and the reasons for any loss to follow-up. Baseline socio-demographic characteristics of participants are presented in Table 4.8.

Table 4.8
Baseline Sociodemographic Characteristics

Characteristic	Number of participants (n=18)	Mean (SD)
Age (Year)		
PEEK	range from 47-67	59.00 (7.58)
CoCr	range from 39-77	60.22 (11.44)
Gender		
Male	9 (50%)	
Female	9 (50%)	
History of denture wearer		
Yes	15 (83.3%)	
No	3 (16.7%)	

Characteristic	Number of participants (n=18)	Mean (SD)
History of periodontal disease		
Yes	8 (44.4%)	
No	10 (55.6%)	
Opposing occlusion		
Complete denture	2 (11.1%)	
Partial denture	13 (72.2%)	
Fully dentate	3 (16.7%)	
No of remaining teeth (lower arch)		
PEEK	10 (range 8-10)	
CoCr	8 (range 7-10)	
No of terminal abutment teeth (lower arch)	1 or 2	

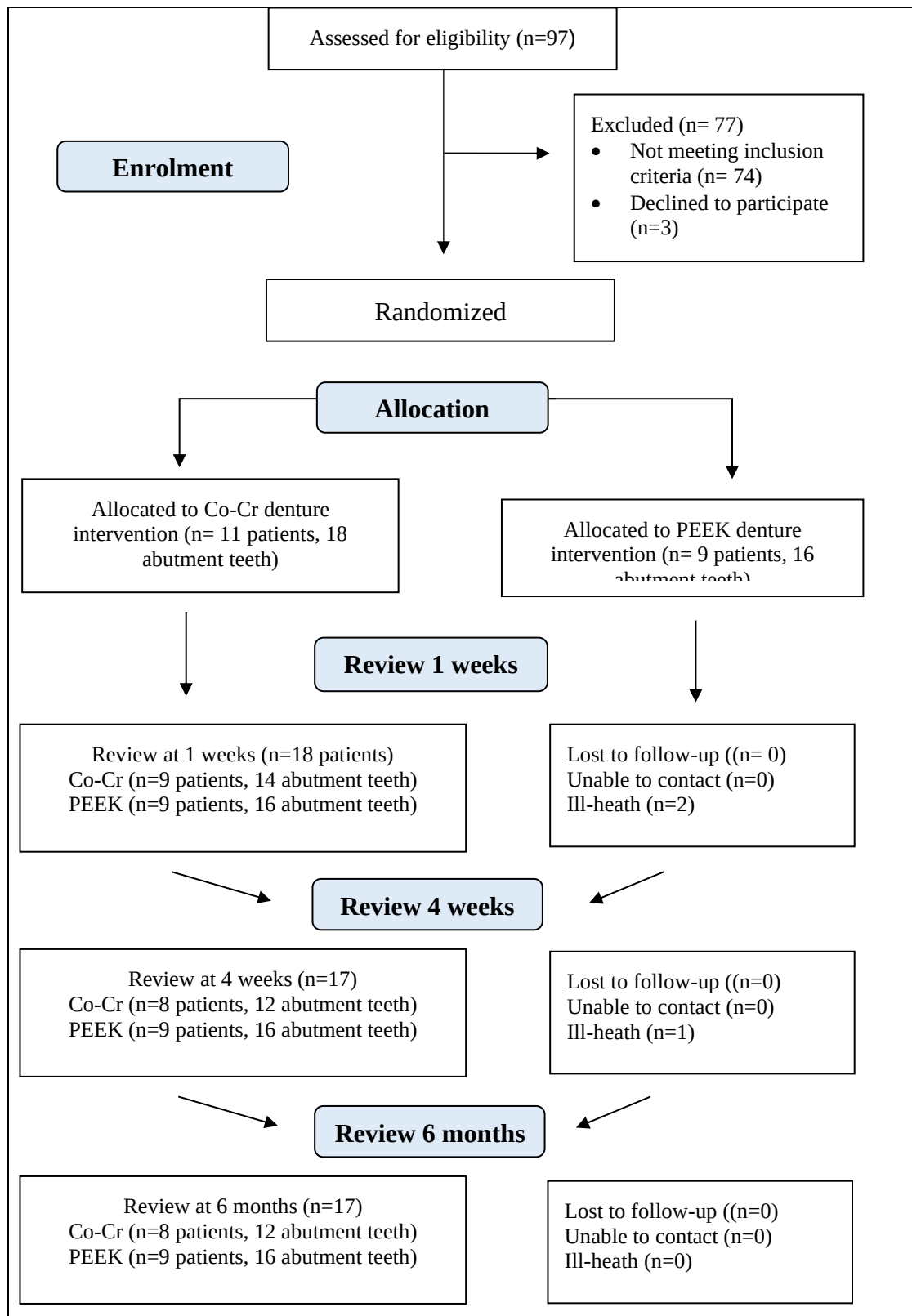


Figure 4.8 CONSORT 2010 Flow Diagram

4.5.2 Clinical and Periodontal Findings at Baseline, 1-month, and Six-month Reviews

Evaluations of terminal abutment teeth were performed at baseline, 4–6 weeks, and 6 months. Table 4.9 shows the descriptive result of the overall finding. Most restorations were confined to the occlusal or buccal surfaces. At 4–6 weeks (one month), no new caries or restoration failures were observed in either group. However, at 6 months, two teeth in the PEEK group required new restorations due to dislodged restorations. The occurrence of new dental caries or dislodged restorations requiring intervention was evaluated using the Cochran Q test (Table 4.10). All CoCr abutments remained clinically sound with no new caries or restoration failures, whereas two PEEK abutments required new restorations at 6 months; however, no statistically significant difference ($p = 0.135$) was found.

Table 4.9
Descriptive Analysis of Caries or Dislodge Restoration that Require New Restoration Occurrence

Intervention	Time	Clinically sound	Teeth with restoration	New caries/required new restoration
PEEK	Baseline	9	7	-
	1-month	9	7	-
	6-month	9	7	2
Co-Cr	Baseline	7	5	-
	1-month	7	5	-
	6-month	7	5	-

Table 4.10
New Dental Caries or Dislodge Restoration that Require New Restoration Occurrence After Intervention Using Cochran Q Test

Intervention	Time	Sound	New caries/dislodge restoration	p-value
PEEK	Baseline	16	0	0.135
	1-month	16	0	
	6-month	14	2	

Intervention	Time	Sound	New caries/dislodge restoration	p-value
Co-Cr	Baseline	12	0	NS
	1-month	12	0	
	6-month	12	0	

NS: not significant

For oral hygiene parameters, both the PEEK and CoCr groups showed comparable baseline Plaque Index and Plaque Score. A reduction was observed at one month, followed by an increase at 6 months, which was more pronounced in the CoCr group (Table 4-11, Figure 4-9).

Table 4.11

Comparison of Mean (95% CI) of Periodontal Parameters between PEEK vs CoCr Based on Time

Parameter	Time	Intervention	Mean finding	95% CI
Plaque index	Baseline	PEEK	0.569	0.426, 0.712
		Co-Cr	0.605	0.454, 0.756
	One-month	PEEK	0.244	0.172, 0.317
		Co-Cr	0.240	0.163, 0.317
	Six-month	PEEK	1.090	0.829, 1.351
		Co-Cr	0.785	0.508, 1.062
Plaque score	Baseline	PEEK	18.791	17.538, 20.046
		Co-Cr	18.068	16.737, 19.398
	One-month	PEEK	14.371	12.298, 16.444
		Co-Cr	12.049	9.850, 14.248
	Six-month	PEEK	25.446	21.367, 29.524
		Co-Cr	28.206	23.880, 32.532
Gingival index	Baseline	PEEK	0.164	0.061, 0.268
		Co-Cr	0.225	0.116, 0.334
	One-month	PEEK	0.097	0.045, 0.149
		Co-Cr	0.064	0.008, 0.119
	Six-month	PEEK	0.353	0.251, 0.456
		Co-Cr	0.256	0.148, 0.356
Bleeding score	Baseline	PEEK	7.190	5.701, 8.679
		Co-Cr	7.484	5.904, 9.063
	One-month	PEEK	5.458	3.931, 6.984
		Co-Cr	4.353	2.734, 5.971
	Six-month	PEEK	10.978	8.994, 12.962
		Co-Cr	9.430	7.326, 11.534

Within-group comparisons demonstrated significant time-based changes in both plaque index and plaque score for PEEK and CoCr frameworks (Table 4-12). In both groups, plaque index increased from baseline to 1 month, indicating an early deterioration in plaque accumulation after denture insertion. By 6 months, the PEEK group showed a significant difference in plaque index compared with baseline ($p = 0.028$) and from month 1 to month 6 ($p = 0.002$). The CoCr group demonstrated a similar decreasing pattern from month 1 to month 6, although the baseline to 1-month change did not reach significance.

For plaque score, both materials showed significant increases at six months compared to both baseline ($p = 0.009$) and the one-month mark ($p < 0.001$). At the six-month period, the mean plaque scores for both PEEK (25.446) and Co-Cr (28.206) were significantly higher than their original baseline values ($p = 0.009$) demonstrating that while oral hygiene initially improved after receiving the frameworks, it significantly regressed by the six-month interval regardless of the material used (Table 4-11, Table 4-12).

Table 4.12

Within-Group Comparison of Plaque Index and Plaque Score Across Time for PEEK and CoCr Frameworks (Repeated-Measures ANOVA).

Clinical finding	Comparison	PEEK		Co-Cr	
		Mean diff (95% CI)	p-value	Mean diff (95% CI)	p-value
Plaque index	Baseline – 1 Month	0.324 (0.174, 0.475)	<0.001	0.365 (0.190, 0.540)	<0.001
	Baseline – 6 Month	-0.521 (-0.984, -0.058)	0.028	-0.180 (-0.643, 0.283)	0.789
	1 Month – 6 Month	-0.845 (-1.306, -0.385)	0.002	-0.545 (-0.912, -0.178)	0.007
Plaque score	Baseline – 1 Month	4.421 (2.598, 6.244)	<0.001	6.019 (3.956, 8.081)	<0.001
	Baseline – 6 Month	-6.653 (-11.45, -1.857)	0.009	-10.139 (-17.348, -2.929)	0.009
	1 Month – 6 Month	-11.074 (-15.712, -6.437)	<0.001	-16.158 (-23.525, -8.790)	<0.001

In terms of the gingival health parameter, the gingival index and bleeding score demonstrated similar patterns, with a mild reduction at 1 month and a subsequent rise at 6 months (Figure 4.10). Within-group comparisons demonstrated no significant change from baseline to 1 month in the gingival index for both groups ($p > 0.05$). By 6

months, the PEEK group demonstrated a significant reduction compared with baseline ($p = 0.043$) and from month 1 to 6 months ($p = 0.041$), while the CoCr group showed a significant decrease only from month 1 to 6 months ($p = 0.012$). These results suggest that gingival inflammation remained stable in the early post-insertion period but improved by 6 months, particularly in the PEEK group.

For the bleeding score, the PEEK group showed no significant change from baseline at 1 month but demonstrated significant reductions from baseline at 6 months and from 1 to 6 months. The CoCr group showed a significant decrease from month 1 to 6 months ($p = 0.002$), whereas the change from baseline to 6 months was not significant ($p = 0.103$). Overall, both frameworks exhibited improvement in gingival bleeding by 6 months, with more pronounced early improvement observed in the PEEK group.

Table 4.13

Within-Group Comparison of Gingival Index and Bleeding Score Across Time for PEEK and CoCr Frameworks (Repeated-Measures ANOVA)

Clinical finding	Comparison	PEEK		Co-Cr	
		Mean diff (95% CI)	p-value	Mean diff (95% CI)	p-value
Gingival Index	Baseline – 1 Month	0.068 (-0.023, 0.159)	0.165	0.161 (-0.010, 0.332)	0.065
	Baseline – 6 Month	-0.189 (-0.372, -0.006)	0.043	-0.031 (-0.238, 0.176)	1.000
	1 Month – 6 Month	-0.257 (-0.381, -0.133)	0.041	-0.192 (-0.337, -0.048)	0.012
Bleeding Score	Baseline – 1 Month	1.732 (-0.436, 3.900)	0.128	3.131 (1.225, 5.037)	0.004
	Baseline – 6 Month	-3.788 (-7.393, -0.182)	0.040	-1.946 (-4.267, 0.375)	0.103
	1 Month – 6 Month	-5.520 (-9.318, -1.722)	0.007	-5.078 (-7.813, -2.342)	0.002

Between-group comparisons showed no significant differences in clinical outcomes between the PEEK and CoCr groups (Table 4.14). These results indicate that, overall, both materials performed similarly with respect to plaque accumulation, gingival inflammation, and bleeding tendency during the study period.

Table 4.14

Between-Group Comparison of Clinical Parameters between PEEK and CoCr Frameworks (Mean Difference $\pm$ 95% CI)

Comparison (PEEK vs Co-Cr)	Mean difference (95% CI)	p-value
Plaque Index	0.091 (-0.053, 0.235)	0.198
Plaque Score	0.095 (-2.716, 2.907)	0.943
Gingival Index	0.023 (-0.072, 0.118)	0.612
Bleeding Score	0.786 (-1.013, 2.586)	0.366

Mean periodontal pocket depth, gingival recession, and clinical attachment loss of terminal abutment teeth are summarised in Table 4.15. At baseline, the mean PPD was comparable between the PEEK (2.55 ± 0.35 mm) and CoCr groups (2.61 ± 0.38 mm), respectively. Similar mean values were observed at 1 month. At the 6-month follow-up, a slight increase in mean PPD was noted in both groups, reaching 2.94 ± 0.35 mm in the PEEK group and 3.07 ± 0.19 mm in the CoCr group.

Mean gingival recession values remained low and unchanged throughout the study period. The PEEK group demonstrated a consistent mean recession of 0.44 ± 0.48 mm at all time points, while the CoCr group showed a mean value of 0.25 ± 0.41 mm from baseline to 6 months. CAL values reflected the combined changes in PPD and gingival recession. At baseline, the mean CAL was 2.96 ± 0.32 mm in the PEEK group and 2.81 ± 0.28 mm in the CoCr group. A slight increase was observed at 1 month and 6 months in both groups, with mean values of 3.36 ± 0.41 mm and 3.31 ± 0.39 mm for the PEEK and CoCr groups, respectively, at the 6-month review. Further analysis found that there were no statistically significant differences in PPD between PEEK and CoCr frameworks at any of the six-probing sites, indicating comparable periodontal tissue response around terminal abutment teeth for both materials (Table 4.16).

Table 4.15

Mean Periodontal Pocket Depth (PPD), Recession and Clinical Attachment Loss (CAL) of Terminal Abutment Teeth at Baseline, 1 Month, and 6 Months

Follow-up	Mean (SD)					
	Baseline		1-month		6 months	
	PEEK	Co-Cr	PEEK	Co-Cr	PEEK	Co-Cr
PPD (mm)	2.55 (0.35)	2.61 (0.38)	2.57 (0.36)	2.54 (0.49)	2.94 (0.35)	3.07 (0.19)
Recession (mm)	0.44 (0.48)	0.25 (0.41)	0.44 (0.48)	0.25 (0.41)	0.44 (0.48)	0.25 (0.41)
CAL (mm)	2.96 (0.32)	2.81 (0.28)	3.01 (0.32)	2.73 (0.46)	3.36 (0.41)	3.31 (0.39)

Table 4.16

Site-Specific Comparison of Periodontal Pocket Depth (PPD) between PEEK and CoCr Frameworks

Periodontal pocket depth	Mean difference (95% CI)	p-value
Distobuccal	-0.028 (-0.334, 0.279)	0.854
Mid-buccal	-0.132 (-0.411, 0.147)	0.340
Mesiobuccal	0.042 (-0.230, 0.313)	0.755
Mesiolingual	0.042 (-0.249, 0.332)	0.770
Mid-lingual	-0.153 (-0.428, 0.122)	0.263
Distolingual	-0.090 (-0.432, 0.251)	0.592

Within-group comparisons demonstrated significant time-dependent changes in PPD and CAL for both framework materials (Table 4.17). In the PEEK group, no significant change in PPD was observed between baseline and 1 month ($p = 0.492$); however, a significant reduction was noted from baseline to 6 months and from 1 month to 6 months ($p < 0.001$).

CAL showed comparable trends. No significant differences were detected between baseline and 1 month for either the PEEK or CoCr groups ($p > 0.05$). In contrast, both groups demonstrated significant increase in CAL level from baseline to 6 months and from 1 month to 6 months. As both groups experience significant increase overtime, this effect is likely related to prostheses adaptation or oral hygiene rather than material specific effect rather than materials specific effect.

Table 4.17

Within-Group Comparison of PPD and CAL Across Time for PEEK and CoCr frameworks (Repeated-Measures ANOVA)

Clinical finding	Comparison	PEEK (n=16)		Co-Cr (n=12)	
		Mean diff (95% CI)	p-value	Mean diff (95% CI)	p-value
PPD	Baseline – 1 Month	-0.021 (-0.059, 0.018)	0.492	0.069 (-0.99, 0.238)	0.807
	Baseline – 6 Month	-0.385 (-0.572, -0.199)	<0.001	-0.458 (-0.796, -0.120)	0.008
	1 Month – 6 Month	-0.365 (-0.549, -0.180)	<0.001	-0.528 (-0.932, -0.123)	0.011
	Baseline – 1 Month	-0.042 (-0.106, 0.023)	0.311	0.063 (-0.108, 0.247)	0.884

Clinical finding	Comparison	PEEK (n=16)		Co-Cr (n=12)	
		Mean diff (95% CI)	p-value	Mean diff (95% CI)	p-value
CAL	Baseline – 6 Month	-0.396 (-0.574, -0.218)	<0.001	-0.500 (-0.847, -0.153)	0.006
	1 Month – 6 Month	-0.354 (-0.523, -0.186)	<0.001	-0.569 (-0.988, -0.150)	0.008

Table 4.18

Between-Group Comparison of Clinical Parameters between PEEK and CoCr Frameworks (Mean Difference $\pm$ 95% CI).

Comparison (PEEK vs Co-Cr)	Mean difference (95% CI)	p-value
PPD	-0.053 (-0.302, 0.196)	0.664
Recession	0.188 (-0.165, 0.540)	0.284
CAL	0.166 (-0.086, 0.417)	0.189

In term of mobility, at baseline and 1 month, all abutment teeth in both PEEK and CoCr groups exhibited no mobility. By 6 months, two teeth in each group demonstrated Grade 1 mobility (PEEK: 2/16; CoCr: 2/12). The Cochrane Q test indicated no statistically significant change in mobility over time for either group ($p = 0.135$), suggesting that the intervention had no clinically meaningful effect on abutment tooth stability during the 6-month follow-up (Table 4.19).

Table 4.19

Tooth Mobility Over Time after Intervention Using Cochrane Q Test

Intervention	Time	Number of teeth		p-value
		No mobility	Mobile	
PEEK	Baseline	16	0	0.135
	1-month	16	0	
	6-month	14	2	
Co-Cr	Baseline	12	0	0.135
	1-month	12	0	
	6-month	10	2	

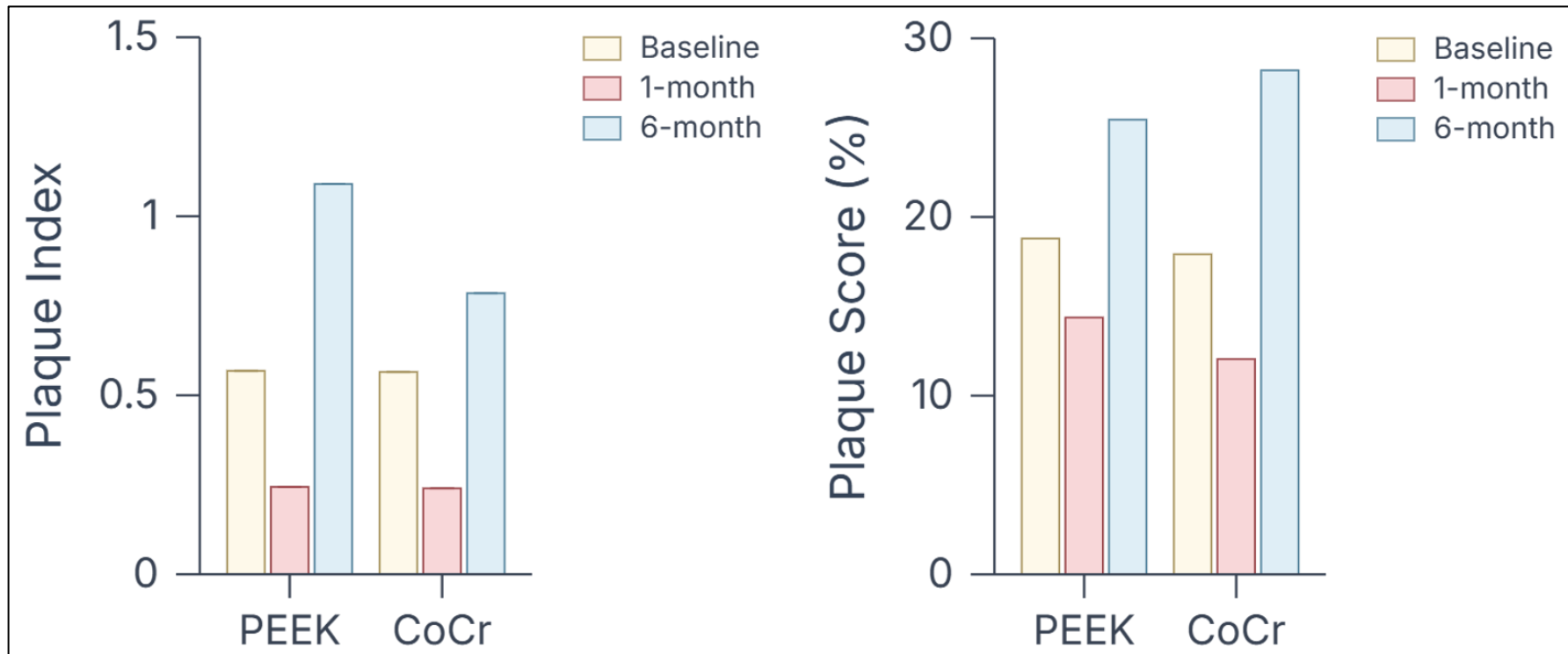


Figure 4.9 Mean of Plaque Index and Plaque Score in PEEK and CoCr Groups across Time Points, Which Reflected the Oral Hygiene Status

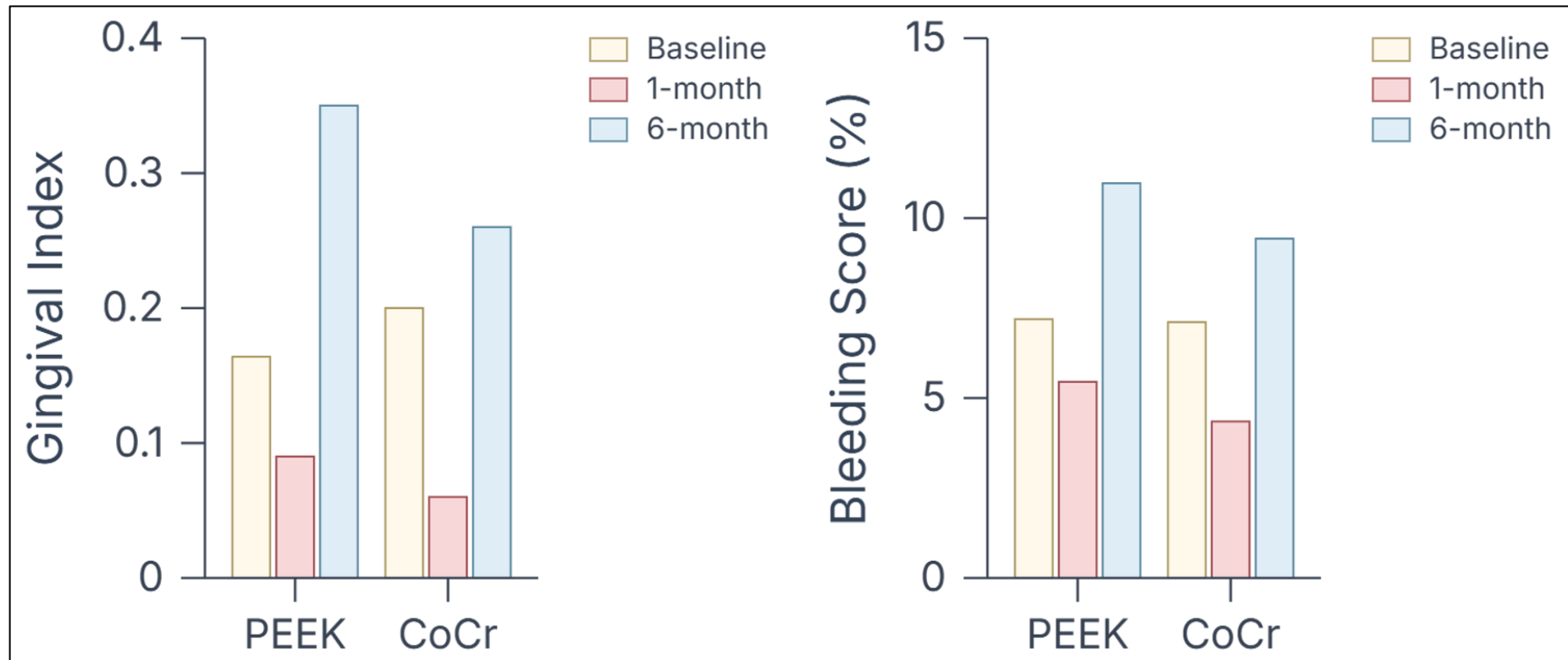


Figure 4.10 Gingival Index and Bleeding Score in PEEK and CoCr Groups across Time Points Which Reflected the Gingival Inflammation Response

4.5.3 Evaluation of the Prognosis of the Abutment Teeth

The prognosis of terminal abutment teeth was assessed at the 6-month follow-up according to clinical and periodontal criteria Table 3.12. In the PEEK group, the majority of abutment teeth (n = 12) demonstrated a good prognosis, characterized by the absence of new caries, no PPD (< 4 mm), and no mobility. Four abutment teeth were classified as guarded, mainly due to dislodged restoration (n=2) and localized pockets up to 4 mm (n=2). No abutment in the PEEK group exhibited a poor prognosis.

In the CoCr group, most abutments (n=10) also showed a good prognosis, while two teeth were graded as guarded due to pocketing more than > 3mm (Table 4.20). No abutment teeth in the CoCr group were categorized as having a poor prognosis. Overall, the distribution indicated more favourable abutment preservation in both groups, with no evidence of tooth loss or severe periodontal deterioration during the study period.

Table 4.20
Prognosis of Terminal Abutment Teeth between PEEK and CoCr RPD

Prognosis	Criteria	Number of teeth	
		PEEK (n=16)	CoCr (n=12)
Good	No caries, PD $\leq$ 4 mm, no mobility	12	10
Guarded	Caries (enamel/dentin), dislodge restoration but teeth are restorable, PD = 4 mm, mobility Grade 1	4	2
Poor	Deep caries/pulpal involvement, PD > 6 mm, Mobility > Grade 1	0	0

4.5.4 Post-Treatment Denture Maintenance Review

After one week, a total of 18 patients were reviewed, including 9 wearing PEEK RPDs and 9 wearing CoCr RPDs. The one-week post-insertion review is a critical phase in RPD treatment to assess the patient's initial adaptation, as well as to identify and evaluate the initial tissue response. During the review phase, all patients were assessed with a standard review protocol, which included assessment of common post-insertion complaints. Patient feedback was recorded, and clinical adjustments were made as necessary.

For PEEK RPDs, four out of nine participants experienced excessive tightness at the clasp areas, particularly on the abutment teeth, causing localized discomfort at the terminal abutment teeth. These patients also reported slight discomfort and difficulty in removing the denture. Clinical examination confirmed localized pressure points around the clasp arms, necessitating minor adjustments to relieve excessive retention. Adjustments were made by relieving the clasp arms by reducing the clasp thickness in the internal surface of the denture to improve ease of insertion and removal without compromising overall retention.

In terms of aesthetics, only one participant expressed concern over the whitish colour of the denture, as the clasp is in the canine region. All patients with clasp at premolar abutment teeth reported no concerns. Despite complaints of discomfort, no ulceration was noted during clinical examination. The patient also did not have any complaints about speech difficulties, premature contact, or occlusion. Interestingly, all patients (n=7) who had previously worn CoCr RPDs preferred PEEK, citing its improved comfort despite initial tightness. They noted that PEEK RPD felt lighter and more secure intraorally, contributing to a more comfortable wearing experience. Participant expressed satisfaction with remarks such as “it feels like part of my mouth” and “it is more comfortable to use than my previous denture.”

In contrast, three out of nine participants with CoCr RPDs reported that their dentures felt slightly loose, particularly around the clasped abutment teeth, although the dentures remained functionally acceptable. Clinical assessment revealed that the CoCr clasps exhibited less retention, which was resolved by slightly tightening the clasp arms to enhance retention and improve overall denture stability. No complaints related to phonetics, aesthetics, or occlusion were reported by the CoCr group. No patients in either group required additional follow-up beyond the one-week review, as all necessary adjustments were completed successfully. Oral and denture hygiene instructions were also reinforced during this visit.

Seventeen participants attended the four- to six-week review (9 PEEK; 8 CoCr), as one patient was unable to attend due to undergoing minor general surgery. Overall, patients demonstrated improved adaptation to their RPDs, with fewer complaints compared to the 1-week review. In the PEEK group, one patient reported persistent clasp tightness, which was corrected during the visit. The three patients who had previously experienced excessive tightness noted that their dentures had become more comfortable over time, with no further pressure-related discomfort.

In the CoCr group, patients who had initially reported looseness confirmed that adjustments made at the 1-week visit had resolved the problem, and their dentures remained stable during function. No new complaints regarding aesthetics, phonetics, or mastication were reported in either group. Clinical examination revealed healthy mucosa without ulcerations or inflammation. No further adjustments were required, indicating successful integration of both types of RPDs within the first month. No further adjustments were required, indicating successful denture integration within the first month of use. Figure 4.11 and Figure 4.12 show the clinical photographs of respondents wearing PEEK and CoCr dentures, presented in anterior, left buccal, and right buccal views.

Seventeen participants returned for the 6-month review (9 PEEK, 8 CoCr). Adjustments were required in 4 patients: two from the PEEK group, who requested trimming of clasp tightness, and two from the CoCr group, who required clasp tightening due to reduced retention.

In the PEEK group, mild to moderate staining was observed on 8 of 9 frameworks, but only one raised a concern about the staining. The discoloration appeared extrinsic in nature and was associated with frequent consumption of chromogenic foods and beverages, such as tea, coffee, and curry. Staining was most pronounced on the lingual plate and at the interface between acrylic resin and PEEK, where micro-gaps may trap pigments and are more difficult for patients to clean (Figure 4.13). Only one respondent exhibited no visible staining on the PEEK framework. This individual reported consciously avoiding staining agents such as tea and coffee and practiced a dedicated denture hygiene routine, including the use of Polident® cleaning tablets once a month, in addition to regular cleaning with soft toothpaste and toothbrush (Figure 4.14).

Unlike CoCr frameworks, which showed no visible staining in this study. All dentures were sent to the prosthodontic laboratory for cleaning and polishing. Dentures were cleaned using polishing paste. Nevertheless, no complaints related to phonetics or occlusion were reported by either group. The summary of review findings for PEEK and CoCr RPDs at 1-week, 1-month, and 6-month intervals is presented in Table 4.21..

Table 4.21

Post-Maintenance Review of PEEK and CoCr RPDs at 1-week, 1-month, and 6-Month Intervals.

Parameter	Group	1-week (n, %)	1-month (n, %)	6-months (n, %)
Adjustment needed	PEEK (n=9)	4,44.4	1,11.1	2, 22.2
	CoCr (n=9)	3,33.3	0,0	2,22.2
Retention	PEEK (n=9)	4, 44.4	1,11.1	2,22.2
	CoCr (n=8)	3,37.5	0, 0	2,25.0
Aesthetic	PEEK (n=9)	1, 11.1	0,0	1,11.1
	CoCr (n=8)	0, 0	0,0	0, 0



Figure 4.11 Anterior View, Left and Right Buccal View of the Respondent that Wear CoCr Framework



Figure 4.12 Anterior View, Left and Right Buccal View of the Respondent that Wear CoCr Framework



Figure 4.13 Staining from a PEEK Denture After 6 months of Wear



Figure 4.14 PEEK Removable Partial Denture Following Removable Partial Denture After Cleaning and Polishing Stage in the Laboratory

4.5.5 Patient-Reported Outcome: OHIP-14

Patient-reported outcomes were assessed using the OHIP-14 questionnaire, with mean scores, domain changes, and statistical comparisons reported. Figure 4.15 shows the mean of total OHIP-14 scores for both groups. The mean total OHIP-14 score for the PEEK group decreased from 26.67 (12.22) at baseline to 13.00 (5.59) after denture placement, indicating a marked reduction in patient-reported oral health impact. A similar pattern was observed in the CoCr group, where the total score reduced from 26.00 (6.06) pre-insertion to 12.66 (7.37) post-insertion (Table 4.22).

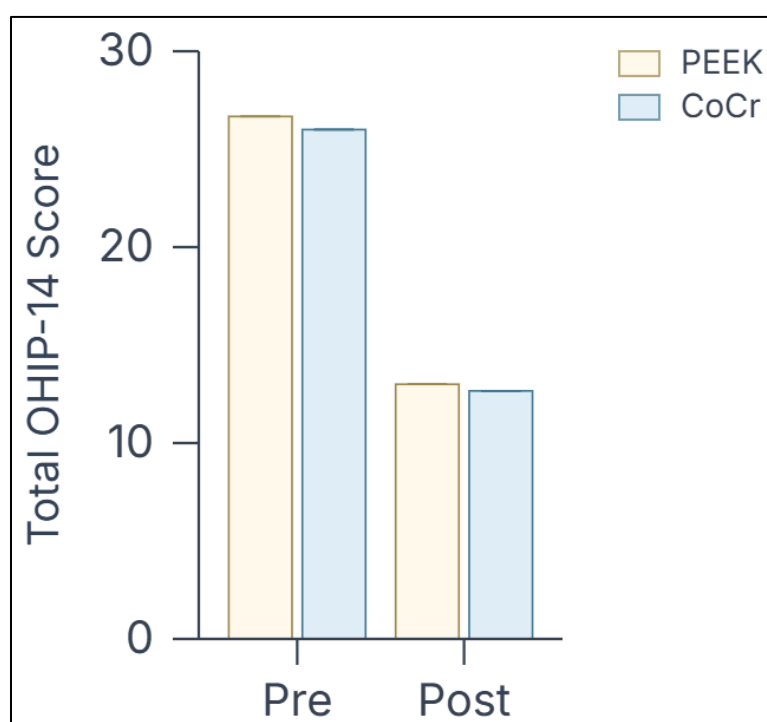


Figure 4.15 Comparison of the Mean of total OHIP-14 Scores Pre- and Post-Treatment in CoCr and PEEK Denture Groups

Table 4.22

Mean and Standard Deviation of Total OHIP-14 Scores Pre- and Post-denture Insertion

	PEEK		CoCr	
	Pre	Post	Pre	Post
Mean (SD)	26.67 (12.22)	13.00(5.59)	26.00 (6.06)	12.66 (7.37)

Figure 4.16 shows the mean scores for each of the seven OHIP-14 domains. When analysed by domain, both groups demonstrated significant improvements across

most domains, indicating that RPDs enhanced patients' OHRQoL. Both the PEEK and CoCr groups demonstrated prominent within-group improvements in OHRQoL following denture insertion, as reflected by reductions across multiple OHIP-14 domains (Table 4.23). In the PEEK group, significant decreases were observed in functional limitation, physical pain, physical discomfort, physical disability, psychological disability, and social disability ($p \leq 0.05$), whereas the handicap domain showed a reduction that did not reach statistical significance ($p = 0.084$). In contrast, the CoCr group showed significant improvements across all seven domains.

Between-group comparison, no statistically significant differences were found between the PEEK and CoCr groups at baseline or after denture insertion (all $p \geq 0.05$) (Table 4.24). This indicates that patients in both groups reported similar levels of functional, physical, psychological, and social impacts prior to treatment, and they experienced comparable improvements after receiving their respective dentures.

Table 4.23

Mean (SD) OHIP-14 Domain Scores at Baseline and Post-denture Insertion in PEEK and CoCr Groups (Within-Group Comparison Using paired T-test)

Domain	PEEK			CoCr		
	Pre, Mean (SD)	Post, Mean (SD)	p-value	Pre, Mean (SD)	Post, Mean (SD)	p-value
Functional limitation	4.33 (2.00)	2.11 (0.60)	0.008	3.56 (1.01)	1.67 (0.87)	<0.001
Physical pain	4.00 (1.32)	2.11 (0.60)	0.002	4.44 (1.33)	2.11 (1.36)	<0.001
Physical discomfort	4.33 (1.73)	2.56 (1.51)	0.003	4.78 (1.79)	2.67 (1.32)	0.001
Physical disability	4.78 (2.33)	2.33 (1.50)	<0.001	5.22 (1.20)	3.00 (1.11)	<0.001
Psychological disability	3.56 (1.74)	1.11 (0.93)	<0.001	2.67 (1.50)	1.11 (1.45)	0.019
Social disability	2.89 (2.26)	1.11 (1.05)	0.043	2.56 (0.73)	0.89 (1.05)	<0.001
Handicap	2.78 (1.79)	1.67 (0.87)	0.084	2.78 (0.83)	1.22 (1.20)	<0.001
Total score	19.00 (8.20)	11.44 (4.98)	0.011	18.56 (3.78)	10.78 (7.21)	<0.001

Table 4.24

Mean (SD) OHIP-14 Domain Scores at Baseline and Post-denture Insertion in PEEK and CoCr Groups (Between-Group Comparison Using Independent T-test)

Domain	Pre			Post		
	PEEK	CoCr	p-value	PEEK	CoCr	p-value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Functional limitation	4.33 (2.00)	3.56 (1.01)	0.303	2.11 (0.60)	1.67 (0.87)	0.527
Physical pain	4.00 (1.32)	4.44 (1.33)	0.303	2.11 (0.60)	2.11 (1.36)	0.134
Physical discomfort	4.33 (1.73)	4.78 (1.79)	0.303	2.56 (1.51)	2.67 (1.32)	0.303
Physical disability	4.78 (2.33)	5.22 (1.20)	0.134	2.33 (1.50)	3.00 (1.12)	0.303
Psychological disability	3.56 (1.74)	2.67 (1.50)	0.134	1.11 (0.93)	1.11 (1.45)	0.303
Social disability	2.89 (2.27)	2.56 (0.73)	0.058	1.11 (1.05)	0.89 (1.05)	0.637
Handicap	2.78 (1.79)	2.78 (0.83)	0.303	1.67 (0.87)	1.22 (1.20)	1.00
Total score	19.00 (8.20)	18.56 (3.78)	0.303	11.44 (4.98)	10.78 (7.21)	0.303

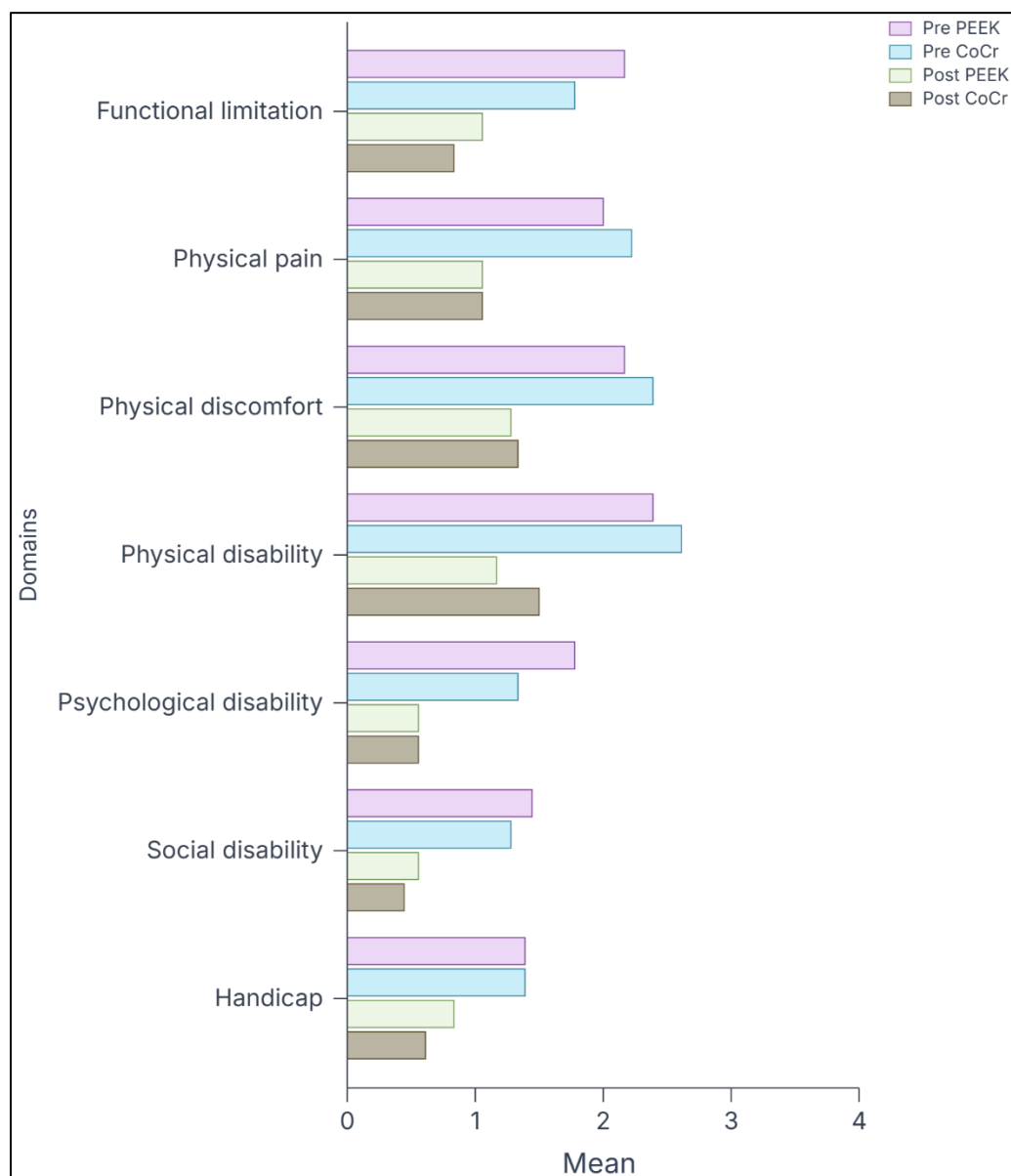


Figure 4.16 Comparison of Average OHIP-14 Domain Scores (Pre vs Post) in PEEK and CoCr Groups.

4.6 Correlation between Finite Element Analysis and Clinical Findings

For clinical study, the lingual plate major connector with a mesial rest was selected for FEA and clinical evaluation due to widespread clinical application in mandibular distal extension cases and its favourable biomechanical characteristics. The FEA was performed to simulate stress distribution and deformation within the PDL and framework under functional loading. Although only one FEA dataset was generated, it served as a biomechanical reference to interpret the corresponding clinical findings. The clinical evaluation focused on the biological response of the terminal abutment teeth

over a 6-month period, including changes in probing pocket depth and tooth mobility as well as if there are any changes in the framework.

In this design, the comparison between PEEK and CoCr demonstrates distinct material-dependent mechanical behaviours with important clinical implications. PEEK produced substantially lower framework stress (286.6 MPa vs. 778.7 MPa). However, this benefit was accompanied by greater framework displacement, with PEEK deforming approximately 2.3 times more than CoCr (Figure 4.17). This increased flexibility may translate into reduced denture stability during function. Although the PEEK stress slightly exceeded its typical elastic limit (around 90-110 MPa), and the CoCr stress approached its elastic limit (around 800 MPa) (Schwitalla et al., 2017; Schwitalla et al., 2015, Kurtz & Devine, 2007). Both materials were predicted by FEA to maintain structural integrity under functional loading. Clinically, no visible framework fractures, deformations, or clasp distortions were observed for either material after six months, consistent with FEA predictions that the induced stresses remained below the failure threshold.

At the abutment teeth (PDL) level, PEEK transmitted 16% less PDL stress, suggesting a protective effect on the supporting tooth, while PDL deformation remained nearly identical between the two materials (PEEK: 0.0866 mm; CoCr: 0.0858 mm). This suggests that, despite the lower PDL stress with PEEK, the functional displacement of the tooth remained essentially unchanged (Figure 4.18). Deformation was primarily concentrated at the cervical region of the abutment, with the VMS distribution revealing slightly higher peak stress in the CoCr model (9.004 MPa) compared to PEEK (7.600 MPa), mainly localized at the middle and toward the apical zones of the tooth. These findings indicate that although both materials produced similar deformation magnitudes, the CoCr framework transmitted higher stress to the PDL due to its greater rigidity. Clinically, this pattern aligns with our observations, as no significant differences in mobility or probing depth were detected between groups during the follow-up period. Although a direct statistical correlation could not be established, the clinical stability of the abutment teeth was consistent with the low stress levels predicted by the FEA model, suggesting a positive agreement between the simulated and clinical findings.

In contrast, the mucosal response revealed a potential drawback of PEEK in this design. PEEK generated nearly double the mucosal stress (0.692 MPa vs. 0.359 MPa for CoCr), approaching the thresholds associated with mucosal discomfort

(approximately 0.25–1.0 MPa depending on intraoral site) (Ogimoto, Ogawa, Sumiyoshi, Matsuka, & Koyano, 2002). Mucosal deformation under PEEK was also more than twice that of CoCr, indicating higher stresses and greater tissue displacement, which could theoretically increase the risk of soreness or trauma. However, patients reported no pain in the residual ridge, and there were no clinical signs of ulceration, soreness, or redness. However, four respondents reported excessive tightness around the clasp. Additionally, OHIP-14 scores showed no meaningful differences between the two materials. These findings suggest that, within the short-term evaluation period, the increased mucosal load predicted by FEA did not translate into observable symptoms or a measurable decline in OHQoL.

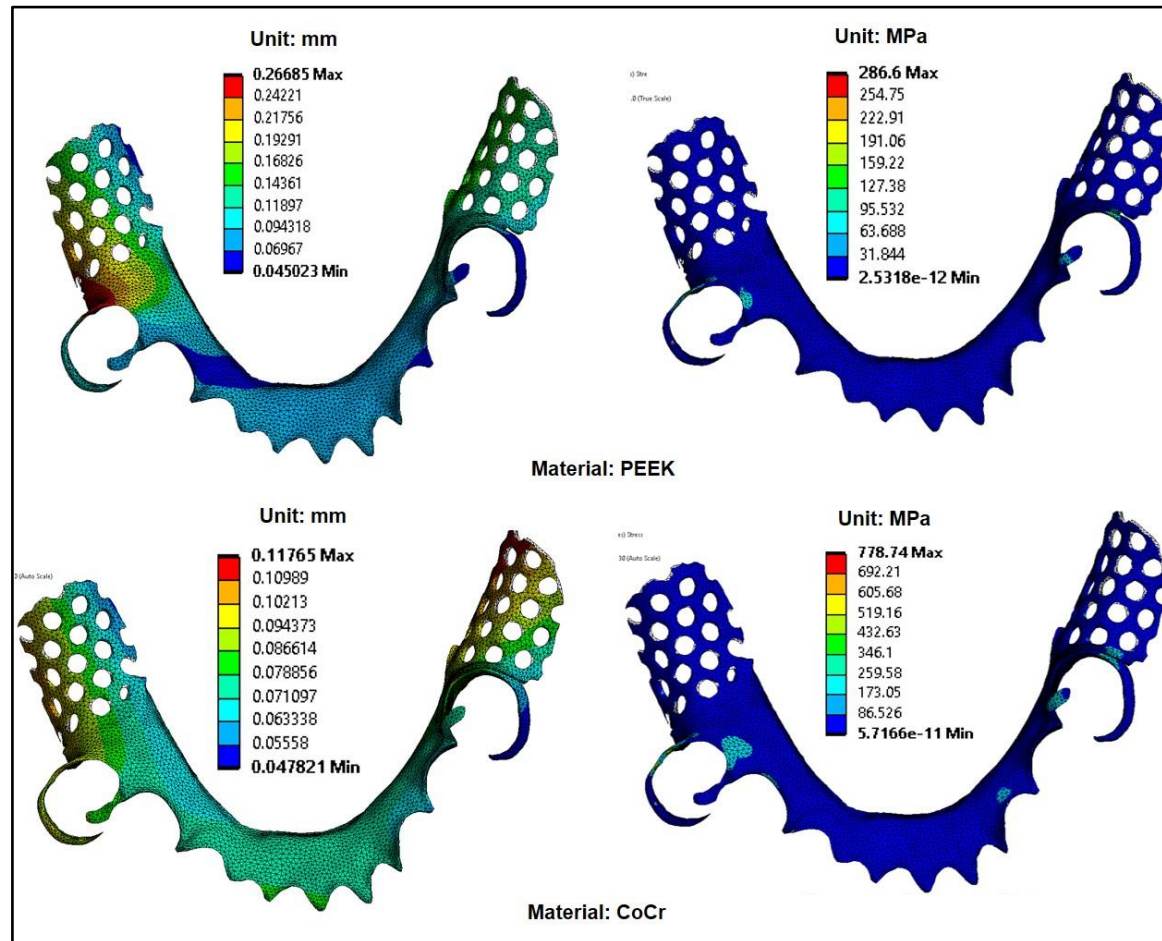


Figure 4.17 Comparison of Deformation and Maximum Von Mises Stress Distribution in PEEK and CoCr RPD Frameworks: CoCr Exhibits Lower Deformation but Higher Von Mises Stress, whereas PEEK shows Higher Deformation but Lower Stress

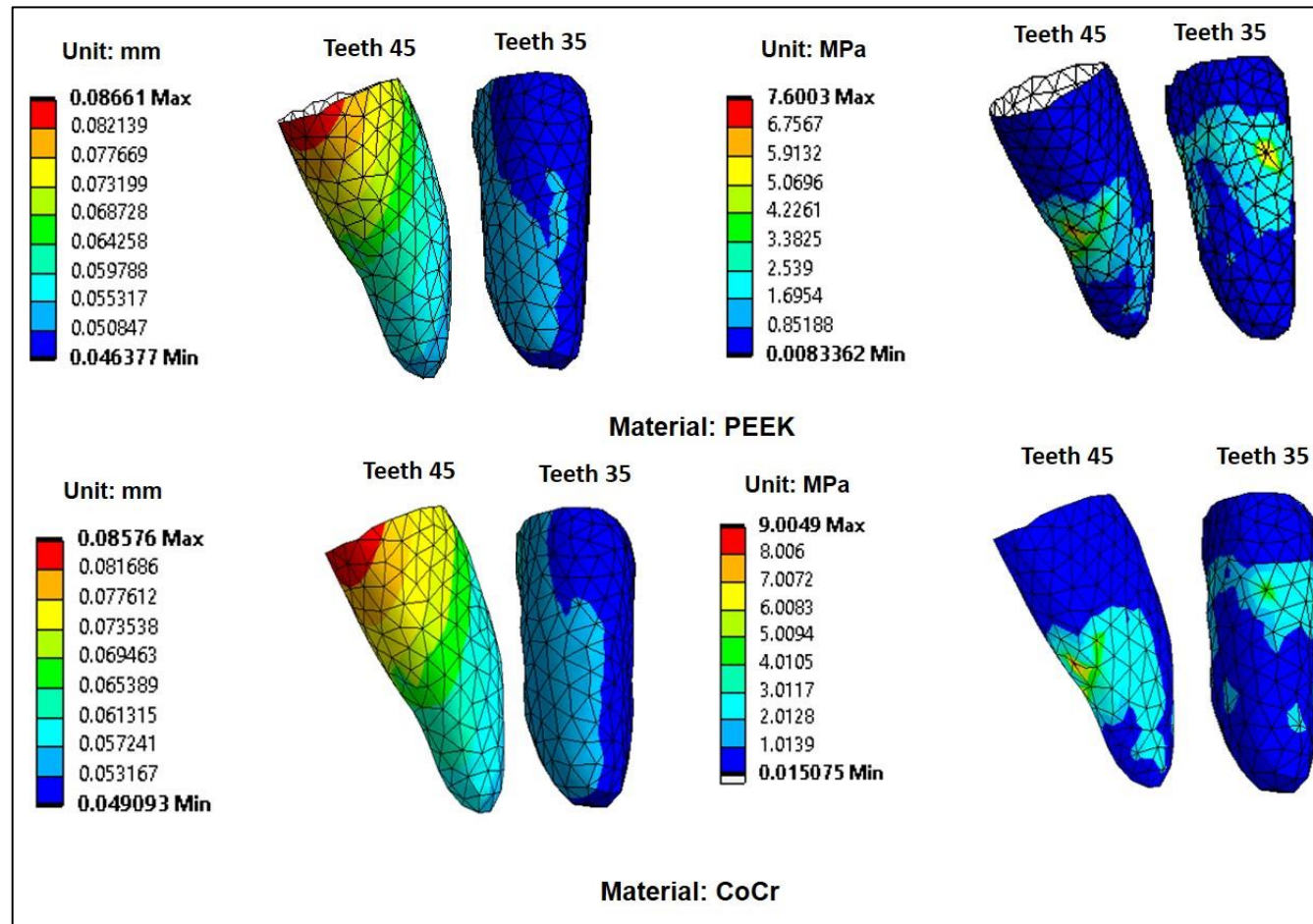


Figure 4.18 Comparison of Deformation and Maximum Von Mises Stress Distribution in PEEK and CoCr RPD Frameworks, Showing Higher Von Mises Stress in CoCr, While Overall Deformation was Similar for Both Materials (0.086 mm vs 0.085 mm)

CHAPTER 5

DISCUSSION

5.1 Introduction

The discussion is organized into two main sections: the first covers the methodology and results of the finite element analysis (FEA), while the second focuses on the clinical study methodology and its corresponding results.

5.2 Discussion of the Methodology: Finite Element Analysis

FEA provided valuable insight into the mechanical response, showing how different framework materials and designs influence stress transfer to the PDL and mucosa, which would be challenging to measure experimentally. One of the major advantages of this approach is its reproducibility and its ability to provide a standardised method for comparing designs under identical conditions. Our study employed FEA to evaluate the biomechanical performance of RPD frameworks incorporating different framework materials, connector configuration, and rest positions in a mandibular Kennedy Class I case. The three-dimensional model was derived from an actual patient, which incorporated relevant anatomical structures, including the abutment teeth, PDL, mucosa, and alveolar bone. While the patient-specific model enhances the clinical relevance of the study, it also introduces a limitation, as the results obtained may not be generalizable to other anatomical variations (Chen et al., 2019). Nonetheless, the use of personalised anatomical data helps to enhance the clinical relevance of the simulation and provides valuable insights for future case-specific prosthodontic planning.

This study did not incorporate validated baseline stress thresholds for all components. Instead, the interpretation of results was based on relative comparisons among different framework designs and materials, particularly for the PDL and mucosa, rather than on absolute stress or deformation values. In this context, validated baseline stress thresholds refer to established, experimentally confirmed limits or reference values for stress that specific materials or biological structures can safely tolerate before damage, deformation, or failure occurs (Oefner et al., 2021). However, such thresholds

vary widely in the literature and are often not universally agreed upon especially for soft tissues like the mucosa and PDL (Fill et al., 2012). As a result, many FEA studies adopt a comparative approach, using relative differences (e.g., higher vs. lower stress) rather than referencing exact failure points. This method is commonly accepted when clinically validated thresholds, such as the maximum allowable stress for the PDL or mucosa, are inconsistent across sources. Nevertheless, the material properties, loading conditions, and finite element method were adapted from Chen et al. (2019), which served as a methodological reference. However, it is important to note that, the study by Chen et al. involved different patient anatomy, model geometry, and denture design due to the use of individual patient-derived data. Despite the absence of validated clinical thresholds, the relative differences in stress and deformation patterns can still guide clinicians in selecting framework materials and designs that are more biomechanically favourable to the abutment teeth and supporting tissues.

Although several optimisation studies have evaluated PEEK clasp geometry (Lee et al., 2024; Peng et al., 2020), similar investigations for major connectors are not available, to our knowledge. In the context of our study, this means that both RPD frameworks were designed based on conventional CoCr design principles, particularly in terms of the major connector dimensions, rest seat location, and clasp configuration which is based on conventional design standards rather than empirical optimization. This standardization was crucial for enabling comparable evaluations across materials, ensuring that differences in biomechanical behaviour could be attributed primarily to material properties rather than to design variations. For the CoCr framework, design parameters such as the major connector dimensions and clasp configuration are well supported by the prosthodontic literature and clinical guidelines (Carr & Brown, 2010; Phoenix et al., 2003). These values have been established and are widely accepted in clinical practice over decades of use. In contrast, PEEK frameworks lack formal, standardized design protocols, and their development is still evolving based on emerging clinical experience. In the absence of evidence-based guidelines, clinicians typically rely on manufacturer recommendations, laboratory protocols, and case reports to guide the design process (Juvora Ltd., 2022; Gray et al., 2021; Zoidis et al., 2016). In our study, the lingual bar for both materials was standardized to 2 mm in thickness and 5 mm in height to allow a direct comparison under identical conditions, in accordance with the accepted range for metal frameworks. Since no specific recommendations currently exist for lingual plate designs in PEEK RPDs,

standardization remains challenging. To ensure consistency, the PEEK lingual plate was designed with a thickness of 1.0 mm, aligning more closely with conventional CoCr designs to enable direct comparison under the same conditions. Similarly, for clasp design, PEEK guidelines recommend a thickness of 2 mm and a height of 3 mm, which are significantly larger than the commonly used 1.0 mm minimum clasp width in CoCr frameworks. However, to preserve aesthetics and ensure standardization across groups, a clasp width of approximately 1.3 mm was used for both materials, although this may fall below the ideal dimensions for PEEK.

In a previous study, the 3D geometrical model of the acrylic portion of the RPD (baseplate/flange) is typically obtained by scanning a conventional denture fabricated over a patient's plaster model using laboratory scanners (Messias et al., 2021). In contrast, our study employed a fully digital approach using the 3Shape Dental System by modifying the "custom tray" function, as the software lacks a dedicated baseplate or flange design tool (Hamid et al., 2025; Russo et al., 2021). This method not only eliminates the need for physical prototypes but also simplifies the design process and enables precise control of baseplate parameters through adjustable digital settings.

All supporting and anatomical structures were modelled as homogeneous, isotropic, and linearly elastic to simplify complex biological behaviour with the exception of the PDL, which was modelled as a viscoelastic material to better reflect its time-dependent response to load (Chen et al., 2019). While this assumption reduces computational complexity and facilitates model convergence, it does not fully capture the nature of oral tissues, which may influence stress distribution in real clinical scenarios. Material properties such as Young's modulus and Poisson's ratio were obtained from published data to approximate realistic mechanical behaviour (Chen et al., 2019); however, variations in reported values among other studies may introduce uncertainty in the accuracy of the model (Lyu et al., 2023; Shahmiri & Das, 2017). Furthermore, the application of boundary conditions aimed to replicate functional forces in Kennedy Class I situations, yet these may not fully capture the variability of occlusal forces during mastication.

Total deformation and VMS were chosen as primary outcome measures, as this is in line with previous studies offers valuable insight into the mechanical performance of the prosthesis (Chen et al., 2019; Shahmiri & Das, 2017). Deformation reflects the framework's flexibility or rigidity under stress, whereas VMS is widely used to predict the risk of material failure or excessive loads on abutment structures. Nevertheless,

these metrics provide a simplified view of clinical performance and do not account for factors such as fatigue behaviour, micro-movements at the tooth-prosthesis interface, or patient-specific variations in bone quality. Despite these limitations, the adopted modelling approach enabled a controlled comparison of designs and materials under standardized conditions, thereby supporting the primary objective of this study.

5.3 Discussion of the Finite Element Analysis Result

This study investigated the biomechanical behaviour of RPD frameworks by comparing two materials (PEEK versus CoCr) in two major connector designs: plate and bar, and different rest positions (mesial versus distal). The assessment focused on deformation and VMS across three critical components: the framework, PDL, and mucosa. It also discusses the clinical implications of these findings, aiming to guide clinicians in selecting the most appropriate material, connector design, and rest configuration based on biomechanical priorities and patient-specific needs.

5.3.1 Influence of Framework Material in Major Connector Design and Rest Position on Biomechanical Performance

The mechanical properties of framework materials, such as stiffness and flexibility, play an important role in determining the overall performance of RPDs and how the denture responds under functional loads. However, these inherent material characteristics do not act in isolation. The design of the major connector significantly modulates clinical performance by influencing force distribution, structural support, and load transfer. In other words, while material stiffness and flexibility are fixed properties, their biomechanical behaviour is strongly influenced by the geometry, coverage, and support provided by the rest and connector design.

No FEA studies to date have compared different mandibular major connector designs made from CoCr alloys. However, *in vitro* investigations have provided valuable insights into how connector geometry influences mechanical performance. Walter et al. (2010) demonstrated that five mandibular major connector designs, fabricated using the same CoCr alloy, produced markedly different deflection patterns under identical loading conditions. The lingual plate showed the least deflection due to its broader coverage and bulk, while the lingual bar exhibited the greatest flexibility.

These findings reinforce that connector geometry and the extent of tissue coverage can enhance or compromise rigidity, even when the material remains constant (Walter et al., 2010). Similarly, Ben-Ur et al., further emphasized the importance of cross-sectional shape by assessing five mandibular lingual bars with varying geometries. Their findings showed that a half-pear-shaped cross-section yielded significantly higher stiffness compared to flatter elliptical forms, particularly under compressive (horizontal) loading (Ben-Ur et al., 1999).

While previous studies focused on CoCr frameworks, a more recent FEA study by Chen et al. compared the mechanical behaviour of CoCr, titanium, and PEEK frameworks under similar loading. However, Chen et al. evaluated only lingual plate major connectors with several clasp configurations, but their findings were presented as averaged outcomes rather than design-specific comparisons. As a result, the influence of individual clasp designs and connector geometry on stress distribution was not clearly distinguished. This limit understanding of how each configuration behaves biomechanically and how material choice interacts with specific design features (Chen et al., 2019).

To overcome this limitation, the comparative analysis in the present study both supports and extends the conclusions of the previous study. The previously reported material-dependent trends are generally validated. For example, in a comparable lingual plate configuration, PEEK demonstrated a protective effect on the PDL (7.60 MPa vs. CoCr 9.05 MPa) and lower framework stress (286.6 MPa vs. 778.7 MPa), consistent with their finding that PEEK experiences substantially lower stress than CoCr. At the same time, our design-specific assessment shows that connector design plays a significant role in stress distribution, a detail that could not be captured by the previous study (Chen et al., 2019).

Similarly, for deformation, Chen et al. reported greater deformation in PEEK frameworks (~0.69 mm) than in CoCr (~0.46 mm), indicating approximately 50% greater deformation in PEEK. Our findings align with this trend, with PEEK exhibiting a deformation range of 0.10–0.79 mm, compared with 0.12–0.28 mm for CoCr. The wider range observed in our study emphasizes that deformation is highly dependent on specific design configurations, highlighting the important role of connector design in biomechanical performance.

Although the PDL stress values in our study (PEEK: 0.80–7.60 MPa; CoCr: 0.92–9.05 MPa) are higher than those reported by Chen et al. (PEEK: ~0.12 MPa; CoCr:

~0.17 MPa), this is likely attributable to clinical differences, such as variations in patient anatomy and Kennedy classification, rather than modeling parameters, which were kept consistent with the previous study. Despite the difference in magnitude, the relative trend is consistent, which is that PEEK frameworks generally produce equal or lower PDL stress compared to CoCr for comparable designs. For example, in the lingual plate with mesial rest configuration, PEEK generated a PDL stress of 7.60 MPa versus 9.05 MPa for CoCr, confirming PEEK's protective effect on abutment teeth.

Mucosal stress findings also showed partial agreement with Chen et al (2019), who reported higher stress for PEEK (~0.74 MPa) than CoCr (~0.59 MPa). In our lingual plate with mesial rest configuration, PEEK similarly produced higher mucosal stress (0.69 MPa vs. 0.36 MPa). However, this pattern did not hold across all connector designs. In lingual bar configurations, mucosal stress remained low and comparable for both materials (approximately 0.07 MPa), indicating that a more rigid major connector enables PEEK to transfer load more efficiently to the abutments rather than the mucosa. This indicates that the effect of PEEK on mucosal stress is design-dependent rather than inherently greater, thereby refining the general conclusions drawn from previous work.

Our study highlights the critical influence of major connector design on load distribution. While bar designs offer clear biomechanical advantages in CoCr frameworks, the choice between bar and plate in PEEK frameworks requires careful consideration to balance reduced mucosal loading against increased abutment tooth stresses. This can be attributed to the material's lower elastic modulus, combined with the smaller cross-sectional area characteristic of the bar design. This configuration provides greater flexibility for the framework, enabling load redistribution away from the mucosa, but at the cost of increased internal stresses within the framework and the PDL. This flexibility arises from PEEK's semi-crystalline polymer structure, composed of both amorphous and crystalline regions, which permits deformation under occlusal loading and facilitates energy dissipation rather than direct transmission of forces to supporting tissues (Yang et al., 2017; Tannous et al., 2012; Kurtz & Devine, 2007).

Apart from the interaction between material stiffness and connector geometry, which alters how occlusal forces are transmitted, the same rest position (mesial or distal) can behave differently depending on the framework material and the type of major connector. The rest position should be selected based on individual clinical priorities, weighing the need for abutment protection against the need for framework stability and soft tissue comfort. A previous study by Mizuuchi et al. has indicated that the different

rest positions and retainers can significantly influence the magnitude of abutment tooth displacement. This suggests that the choice of rest position is meticulously correlated with the material's elastic modulus and the connector's geometry to optimize force distribution and minimize biomechanical complications (Mizuuchi et al., 2002). Furthermore, the elasticity of the supporting PDL can also significantly influence force absorption, especially when considering the differing modulus of elasticity of various materials like PEEK versus more rigid alloys (Chen et al., 2019).

Clinically, mesial rest seats have been favored in distal extension cases as they direct occlusal forces more axially along the long axis of the abutment tooth, thereby minimizing tipping forces and improving stress distribution. In contrast, distal rest seats are believed to create a lever effect, increasing rotational movement around the abutment teeth and potentially amplifying stress on both the supporting mucosa and abutment teeth (Carr & Brown, 2010; Shahmiri et al., 2014).

To better understand the role of rest position, comparisons were also made across both plate and bar designs in different framework materials. Interestingly, our findings revealed material-dependent variations in the optimal rest position, even within the same plate design. This difference suggests that the mechanical behavior of the framework is strongly influenced by the material's stiffness and flexibility. When a lingual plate is combined with a mesial rest, PEEK performs optimally as it produces the lowest PDL stress, demonstrates markedly lower internal framework stress, and therefore offers a protective biomechanical environment for a weakened abutment tooth. The only drawback is its substantially higher mucosal stress (0.69 MPa), which may predispose to mucosal soreness. In this configuration, PEEK remains the material of choice provided that soft-tissue monitoring and periodic adjustments are prioritised.

In contrast, combination a lingual plate with a distal rest shifts the biomechanical advantage entirely to CoCr. The distal rest introduces an unfavourable lever arm that increases rotational movement of the distal extension base. In a material with lower elastic modulus such as PEEK, this rotational tendency is amplified, resulting in greater framework displacement and elevated mucosal strain, potentially compromising clinical stability. This aligns with previous *in vivo* findings by Kawata et al., who reported that distal rests produced lower force on the abutment tooth compared to mesial rests, despite directing forces more posteriorly (Kawata et al. 2008). Similarly, Suenaga et al. observed reduced abutment loading with distal rests, although ridge loading increased (Suenaga et al. 2014).

Thus, from a clinical perspective, this suggests that mesial rest placement may be preferred when the goal is to enhance framework stability and soft tissue preservation, whereas distal rest placement may be more advantageous when tooth protection is prioritized. Therefore, the choice of rest position should be guided by the clinical objective, whether to prioritize framework and tissue preservation or to minimize stresses on the abutment tooth.

To date, the only FEA study directly focused on occlusal rest design is that of Lyu et al., which did not compare mesial and distal positions but instead examined how dimensional and geometric parameters (such as thickness, width, and the radius of curvature) affect stress distribution in PEEK and zirconia occlusal rests. (Lyu et al., 2023). Their findings indicated that zirconia rest possessed sufficient flexural and fatigue strength for use in conventional designs. In contrast, while PEEK rests met the required flexural strength when the thickness was at least 1.5 mm and the width at least 3.0 mm, they consistently fell short of the fatigue strength threshold, raising concerns about their long-term durability. While these findings focus on rest geometry rather than position, they highlight the importance of material properties when determining rest configuration, as the mechanical limitations of PEEK may influence whether a mesial or distal rest is more appropriate for sustained clinical use. Interestingly, a classical randomized controlled trial found no significant difference in the effect on abutment teeth between RPDs with mesial rests (RPI system) and those with distal rests and circumferential clasps, suggesting that rest seat location may be less critical than occlusal scheme and other case-specific factors (Kapur, Deupree, Dent, & Hasse, 1994).

5.3.2 Clinical Recommendations for RPD Design Based from FEA Study

These results highlight the importance of both material selection and major connector design in optimizing the biomechanical performance of RPDs. Deformation and VMS provide complementary insights into RPD framework performance as deformation reflects the flexibility of the material while VMS predicts the likelihood of material failure.

For patients with metal sensitivity, PEEK bars may serve as a viable alternative to conventional metal frameworks, as they produce low mucosal stress and moderate PDL stress. However, due to the higher internal stress within the framework, reinforcement is essential to reduce the risk of material failure (Zoidis et al., 2016;

Schwitalla et al., 2015). If reinforcement cannot be achieved, such as in situations with limited space or other clinical constraints, a lingual plate can be used, but only in cases with strong abutments and good residual ridge support due to its greater stress transmission to supporting tissues. Our study found that the PEEK plate design appears more appropriate for patients with compromised abutment teeth, as it tends to reduce stress on the PDL, despite transmitting higher loads to the mucosa. This observation aligns with previous studies, which reported that PEEK plate designs provide better protection for the PDL and promote a more uniform distribution of masticatory forces compared with conventional metallic frameworks, thereby offering potential advantages for patients with reduced periodontal support (Chen et al., 2019).

CoCr bars remain the most favourable choice in patients with good periodontal support, as they effectively reduce PDL stress while distributing load toward the mucosa. In contrast, CoCr plates should be reserved for cases with strong abutments, since stress is largely concentrated on the abutment teeth.

The selection of rest position should be individualized based on the clinical priority, whether to preserve the abutment tooth, maintain residual ridge health, or maximize denture stability. In PEEK plate designs, a distal rest may be preferable when the goal is to protect the abutment tooth, whereas a mesial rest is advantageous when framework stability and patient comfort are prioritized. In PEEK bar designs, the mesial rest provides superior framework and mucosal support, thereby reducing structural deformation and soft-tissue displacement. In contrast, a distal rest provides better PDL protection by limiting stress transmission to the abutment tooth. For CoCr plates, the distal rest position is more favourable because it consistently reduces both PDL and mucosal stress, thereby promoting biomechanical balance and abutment preservation. In CoCr bar designs, the mesial rest is recommended when protecting the PDL is the priority, whereas a distal rest may offer better tissue adaptation and framework stability due to reduced deformation.

Overall, these results highlight the importance of integrating material properties, connector configuration, and rest position into individualized RPD design. A uniform design approach is insufficient as clinicians must tailor each framework design according to patient-specific factors such as periodontal health, ridge condition, and occlusal dynamics.

5.4 Discussion of Methodology Clinical Study

5.4.1 Study Design

This single-centre, clinical study adopted a parallel-group design, in which each participant received only one type of RPD framework; either PEEK or CoCr, a design approach consistent with that employed by previous study (Zhai et al., 2025). This approach was chosen because the study aimed to evaluate clinical and periodontal parameters over time. The use of a single prosthesis may lead to changes in oral tissues, periodontal health, and patient adaptation. If participants were to switch to a second prosthesis, these changes could influence the outcomes associated with the second framework, introducing bias. A parallel-group design reduces confounding carry-over effects and facilitates continuous, unaltered assessment of the effect of each material (PEEK or CoCr) on the abutment teeth and supporting tissues. This enhances the internal validity of the results. Moreover, a crossover design would significantly extend the study duration and require participants to undergo multiple adaptation periods, making it less practical (Hemming et al., 2020).

In contrast to the present study's parallel-group design, two clinical trials by adopted crossover designs to compare PEEK and CoCr frameworks in RPD (Ali et al., 2020; Mohamed & Rasha, 2019). A study by Mohamed & Rasha (2019) evaluated ten participants who wore both metal and PEEK framework for three months each, followed by satisfaction questionnaires. Although this crossover design compared patient-centred outcomes such as retention, comfort, and aesthetics, it failed to account for potential biological effects from the first prosthesis that could influence the response to the second prosthesis. Periodontal tissues, mucosal adaptation, and occlusal dynamics may not fully restore within a short washout period, introducing carry-over bias. Additionally, the study did not report the implementation of a biological washout period, oral prophylaxis, or tissue re-evaluation between phases. Therefore, although the study found improved satisfaction with PEEK, the crossover design limits the strength of conclusions regarding biological tissue response.

Similarly, Ali et al. (2020) conducted a randomized controlled crossover trial to evaluate the effect of PEEK versus CoCr frameworks on oral health-related quality of life (OHRQoL), denture satisfaction, and periodontal indices in patients. Participants wore each framework for 4 weeks, after which they selected their preferred RPD;

further observation was conducted at 6 months and 1 year. Although the study found significant improvements in OHRQoL for both materials, it reported no significant differences in patient preference, satisfaction scores, or periodontal health outcomes (Ali et al., 2020). Notably, while a full-mouth prophylaxis was performed before switching frameworks, 4 weeks may not be sufficient to reverse early inflammatory or adaptive responses, especially in terms of PDL or mucosal remodeling (Knight et al., 2016). Additionally, grouping patients by their preferred framework after the crossover phase could introduce selection bias into long-term comparisons, further complicating interpretation.

While crossover designs are methodologically interesting in controlled settings, their application in RPD clinical trials is constrained by methodological and biological limitations. Prosthodontic interventions such as RPD involve biological adaptation and long-term observation. The effects of one framework on periodontal tissues and mucosa could compromise the evaluation of the second framework. Moreover, requiring patients to switch prostheses could lead to dissatisfaction or increased dropout rates, thereby affecting study retention and overall feasibility. Thus, the parallel-group design used in the present study offers greater validity by eliminating carry-over effects and allowing uninterrupted observation of each framework's clinical impact over time (Lim & In, 2021).

5.4.2 Patient Recruitment and Sample Size

Although the initial sample size calculation required 11 abutment teeth per group, the target was increased to 15 per group to account for potential dropouts. At study completion, 16 abutment teeth were evaluated in the PEEK group and 12 in the CoCr group, following one medically related participant withdrawal. These abutments corresponded to 9 patients in the PEEK group and 8 in the CoCr group. Despite this slight reduction, the final sample remained close to the intended target and was sufficient to maintain the validity of the comparative analysis. Notably, the number of participants evaluated in the present study compares favourably with previous clinical investigations (Iwaki et al., 2024; Reslan et al., 2021; Mohamed & Rasha 2019).

Most clinical studies on PEEK RPDs have involved relatively small sample sizes, typically ranging from 10 to 30 participants (Hegazi et al., 2025; Oliveira et al., 2025; Yoon et al., 2024; Mohamed & Rasha, 2019). For example, Mohamed & Rasha

assessed patient satisfaction with PEEK versus metal RPDs in a cohort of only 10 participants, while another clinical trial on three-dimensionally printed dentures included 18 participants (Iwaki et al., 2024; Mohamed & Rasha, 2019). Among studies evaluating periodontal parameters, only two share a similar scope with the present research (Ali et al., 2020; Zhai et al., 2025). Although Ali et al. initially recruited 26 participants, the sample declined to 21 at six months and 19 at one year due to attrition. Similarly, Reslan et al. reported periodontal outcomes for different extracoronary attachment designs in only 14 well-motivated patients, further illustrating the modest sample sizes typically seen in RPD-related clinical studies (Reslan et al., 2021).

Given that only a limited number of studies specifically examined periodontal parameters in PEEK versus CoCr RPDs, the inclusion of 17 participants in the present study aligns well with the sample size range of comparable research. In total, 28 terminal abutment teeth were analysed, allowing for a focused, framework-level evaluation based on terminal abutment tooth response. In Ali et al., periodontal measurements were recorded for both abutment and non-abutment teeth, with an average of 14 remaining teeth per participant, of which seven served as abutments (range 3–13). In contrast, Zhai et al. did not specify the number of abutment or non-abutment teeth assessed per participant, thereby limiting the comparability and reproducibility of their periodontal findings (Zhai et al., 2025; Ali et al., 2020).

Unlike previous studies, the present research achieved nearly complete participant follow-up and adopted stricter inclusion criteria, recruiting only patients with Kennedy Class I edentulism, with premolars as terminal abutments. This approach enhanced uniformity and minimized confounding variables, thereby strengthening the internal validity of the findings. While this approach enhanced internal validity, it also made participant recruitment more challenging. Additionally, the single-centre design further limited the available patient pool. Nevertheless, considering the complexity of clinical prosthodontic research and the expected challenges in long-term retention, the final sample is considered adequate and methodologically robust for drawing meaningful conclusions.

5.4.3 Denture Design

In this study, a lingual plate major connector was selected for all participants, regardless of whether the framework was fabricated from PEEK or CoCr. This decision

was primarily based on practical considerations related to patient recruitment and anatomical suitability. While a lingual bar is often preferred for its minimal coverage, it requires a minimum of 8-10 mm vertical space between the gingival margin and the functional depth of the lingual sulcus, making it less feasible in many clinical cases. In contrast, the lingual plate requires only about 7 mm of space, making it more adaptable to the anatomical limitations commonly found in a partially edentulous mandibular arch (Phoenix et al., 2003). Recruiting patients for Kennedy Class I cases posed a significant challenge, as many potential participants presented with Kennedy Class I modifications, periodontally compromised abutments, endodontically treated teeth, or crowned abutments, all of which were excluded under the study's strict inclusion criteria. The lingual plate design therefore allowed broader eligibility without compromising prosthodontic principles, enabling the study to achieve the target sample size. Clinically, the lingual plate offers broad tissue contact for enhanced stability, indirect retention, and support for weakened teeth when needed (Phoenix et al., 2003). Standardizing the major connector design also ensured that differences in clinical outcomes could be attributed to the framework material rather than connector variation.

While one clinical study has provided detailed evidence-based design specifications for PEEK frameworks, these recommendations were based on a lingual bar design rather than a lingual plate (Oliveira et al., 2025). To date, no published clinical or in vitro studies have established optimal dimensions for PEEK lingual plate connectors, despite their frequent use in cases with limited vertical space. Existing recommendations focus mainly on increasing thickness to compensate for the material's lower rigidity. In this study, the final denture design incorporated a lingual plate with a minimum thickness of 1.3 mm, mesial rests following conventional CoCr dimensions of 1.0–1.3 mm, and a C-clasp assembly measuring approximately 1.0–1.3 mm. Based on manufacturer recommendations and evidence from case reports, a 0.5 mm undercut was adopted to ensure consistency and patient comfort, despite literature reporting alternative undercut depths of 0.25 mm and 0.75 mm (Juvora Ltd., 2022; Gray et al., 2022). For aesthetic reasons, clasp width was minimized to approximately 1.0-1.3 mm, even though some studies have suggested shorter, thicker and broader clasp designs for enhanced retention (Peng et al., 2024; Gray et al., 2021).

5.4.4 Clinical Procedure

Participants attended eight to nine clinical sessions, from initial impressions to final follow-up at 6 months. Although allocation was concealed until framework try-in, blinding could not be maintained because of the distinct appearance of PEEK and CoCr frameworks, rendering the trial open-label. This limitation may have influenced subjective outcomes and clinical assessments, as the same clinician who delivered the prostheses also recorded periodontal parameters, potentially introducing assessment bias despite the use of standardized protocols. Future studies could adopt additional strategies, such as involving separate clinical and evaluation teams, to further minimize this risk.

The conventional method was used for secondary impressions instead of digital scanning due to its superior accuracy in capturing soft tissue details, functional movements, and deep undercuts, especially in distal extension areas. Intraoral scanners still face limitations in fully edentulous or partially edentulous arches, where tissue compressibility and movement can significantly impact fit (Pereira et al., 2021; Tasaka et al., 2019). Additionally, maintaining a conventional impression technique enabled border moulding and improved control over the final prosthesis adaptation. All clinical procedures were performed by a single clinician using standardized protocols to minimize variability and ensure consistent outcomes.

In this study, both clinical and periodontal parameters were assessed to evaluate the biological response of terminal abutment teeth following RPD insertion. Similar to Ali et al, PI, GBI, and PPD were selected as key indicators because they reflect plaque accumulation, gingival inflammation, and early periodontal changes, which are critical in evaluating the impact of prosthesis design and material on abutment teeth (Ali et al., 2020). In addition, plaque and bleeding scores provide complementary insights into local tissue response and hygiene maintenance, whereas tooth mobility and gingival recession were included to detect potential biomechanical and long-term periodontal effects. Together, these parameters provided a comprehensive evaluation of the short-term biological and mechanical responses of terminal abutment teeth; however, longer follow-up would be required to confirm the progression of attachment or mobility changes over time.

The post-operative denture hygiene instructions were delivered verbally in this study. However, standardisation using a written pamphlet is recommended in future

studies to ensure consistent patient education and compliance. This is particularly important as plaque and bleeding scores were evaluated, and variations in patient understanding or adherence to oral hygiene instructions may influence these outcomes. The use of a standardised written guide may help minimise variability and improve the reliability of periodontal-related clinical measurements.

The follow-up schedule at 1 week, 1-month, and 6 months was designed to monitor early and mid-term responses of abutment teeth to RPD frameworks. The 1-week review focused on immediate adaptation, identifying pressure areas and reinforcing oral hygiene. At 1-month, functional adaptation and early tissue changes, such as plaque accumulation or gingival inflammation, were assessed. The 6-month review provided insight into the mid-term impact of the frameworks on periodontal health, detecting any progressive changes such as increased probing depth, gingival recession, or tooth mobility. While 6 months may not reflect long-term effects, it represents a critical period for detecting biological changes and initiating timely intervention (Ali et al., 2020). Nevertheless, longer follow-up, ideally 12 months or more, would provide stronger evidence of the impact of RPD frameworks on oral mucosa (Hegazi et al., 2025).

5.5 Discussion on the Clinical Study

5.5.1 Socio-demographic Characteristics of Participants

In this study, although 20 patients were initially recruited, only 18 completed denture insertion and baseline assessments for periodontal and OHIP questionnaires. Of these, 17 patients were available for the 1-month and 6-month reviews. Attrition was primarily due to health-related issues, including two patients who did not proceed with denture construction and one who underwent surgery after the denture delivery. The missing data were treated as a complete-case analysis, meaning only patients with full follow-up data were included in the 1-month and 6-month comparisons. This method keeps the analysis straightforward but may introduce bias if patients who dropped out differed from those who remained. However, since the dropouts were due to health issues rather than denture problems, the effect on the reliability of our clinical and patient-reported outcomes is likely small.

In this study, participants ranged from 47 to 67 years (mean 59.00) in the PEEK group and 39 to 77 years (mean 60.22) in the CoCr group. Age may have influenced the clinical outcomes, as it affects periodontal support, bone density, and occlusal force. Younger individuals typically generate higher bite forces, whereas older patients may exhibit reduced occlusal load and adaptive changes in supporting tissues. However, age group standardisation was not feasible due to recruitment challenges.

5.5.2 Clinical, Periodontal Parameters and Prognosis of Terminal Abutment Teeth

Current literature on RPDs has predominantly focused on periodontal parameters, with limited attention to broader clinical outcomes such as caries incidence, restoration failure or prognosis of terminal abutment teeth. This study evaluated clinical, periodontal, and prognostic outcomes of mandibular premolars as standardized terminal abutments, providing a more comprehensive assessment of RPD.

Both PEEK and CoCr frameworks demonstrated comparable overall clinical outcomes. In the CoCr group, no restorations failed and no new caries developed. In contrast, two restorations in the PEEK group required replacement by six months; however, advanced statistical analysis revealed no significant differences in caries incidence or restoration dislodgement. The observed PEEK dislodgements may be attributed to the clasps engaging a relatively deep 0.5 mm buccal undercut, thereby generating levering forces during insertion and removal that could lead to debonding of the restoration.

Our study showed an initial increase in plaque score at one month, followed by significant reductions by six months in both groups. The PEEK group showed a particularly noticeable improvement, which may suggest enhanced plaque control over time. Gingival health was similarly affected, with significant improvements observed in the PEEK group by six months, suggesting that this material may play an important role in periodontal health. However, the lack of significant differences between groups highlights the need for careful consideration when selecting the materials based on individual patient needs and circumstances.

Currently, only two clinical studies have evaluated periodontal outcomes in PEEK RPDs, with Ali et al. (2020) and Zhai et al. (2025) being the primary examples. (Ali et al., 2020; Zhai et al., 2025). Ali et al. conducted a crossover RCT involving

participants with good baseline periodontal health, whereas Zhai et al. employed a parallel-group RCT in participants with mild gingival inflammation and abutment tooth mobility $\leq$ II. Both studies reported no significant differences in periodontal outcomes between PEEK and CoCr frameworks after one year. However, differences in study design, baseline periodontal status, and assessment methods were notable. Ali et al. conducted a comprehensive evaluation that included PPD, plaque index (PI), and gingival bleeding index (GBI), whereas Zhai et al. limited their assessment to tooth mobility and GBI. These variations may explain why Ali et al. observed stable periodontal conditions across both groups, whereas Zhai et al. reported greater periodontal changes, although no material-specific differences were detected.

In contrast to these previous studies, the present study standardized the terminal abutments to mandibular premolars, ensuring consistency across participants. Prior studies included mixed arch designs and variable abutment types, potentially introducing variability in periodontal and clinical outcomes. Furthermore, this study evaluated a broader range of periodontal parameters, including PPD, clinical attachment level (CAL), gingival recession, plaque, and mobility, providing a more comprehensive assessment than previous research. Despite these methodological enhancements, our findings are consistent with prior reports, showing no significant differences between PEEK and CoCr frameworks across any periodontal parameter. This supports the idea that both materials exert comparable biological effects on supporting tissues in the short term.

PPD remained within the healthy range throughout the six-month follow-up, with only a slight increase observed at six months. This increase was higher than that reported by Ali et al., which may reflect differences in baseline periodontal conditions or oral hygiene practices among the study populations. Although the PEEK group demonstrated a slightly smaller increase in PPD, this difference was not statistically significant. The trend may be related to the smoother surface characteristics and lower plaque affinity of PEEK as previously reported (Akl & Stendahl, 2022; Khurshid, Nedumgottil, Ali, Bencharit, & Najeeb, 2022), suggesting a potential influence of material properties on short-term periodontal response. Nevertheless, the absence of significant site-specific differences indicates that framework material alone does not independently affect PPD within the study period.

Gingival recession remained stable in both groups, indicating that neither the PEEK nor the CoCr framework promoted apical migration of the gingival margin.

Overall, the stability of PPD and CAL, and the absence of gingival recession, suggest that both framework materials are biologically compatible with the surrounding soft tissues. Minor variations in plaque and bleeding scores highlight the continued importance of patient oral hygiene practices for maintaining periodontal health during RPD wear.

CAL remained stable in both PEEK and CoCr groups over six months, indicating preservation of periodontal support around the terminal abutments. The stability of CAL, together with PPD and gingival recession, reinforces that short-term periodontal health is primarily influenced by oral hygiene and patient compliance rather than the choice of framework material (Carra et al., 2020). Maintaining CAL is particularly important, as attachment loss is a strong predictor of long-term abutment tooth failure following RPD delivery. Therefore, the absence of significant CAL changes further supports the biological compatibility of both framework materials in the short term.

In this study, the prognosis of abutment teeth was evaluated using a classification that incorporated both clinical and periodontal parameters. The inclusion of caries status was important, as abutment teeth are highly susceptible to plaque accumulation and caries development around rest seats and clasp assemblies, which can compromise their long-term survival. Periodontal assessment, based on PPD and mobility, was also considered essential since attachment loss and tooth mobility have been consistently identified as strong predictors of abutment failure in RPD (Zhai et al., 2025).

While the 6-month follow-up period enabled early detection of clinical and periodontal changes, it may be insufficient to capture the long-term biological response and potential cumulative effects of RPD wear. Periodontal breakdown, tooth mobility, and secondary caries may progress gradually over time, especially under chronic stress and in patients with suboptimal oral hygiene. Therefore, although this mid-term evaluation provides valuable preliminary data on material behaviour and tissue response, longer observation periods (e.g., 2 to 5 years) would be necessary to assess the true prognosis of abutment teeth and the long-term biocompatibility and performance of the framework materials. Nonetheless, the 6-month interval remains clinically relevant, as it represents a critical period of prosthesis adaptation and patient compliance, during which early intervention strategies can still be implemented to prevent long-term complications. These clinical and periodontal outcomes highlight the

importance of assessing not only prosthesis function and retention but also the health of the supporting abutment structures.

Our study highlights the comparable performance of PEEK and CoCr frameworks and emphasizes the potential benefits of PEEK in promoting oral hygiene and gingival health over time. While RPDs can complicate the oral environment and promote plaque accumulation, good oral hygiene and regular maintenance visits are essential to minimizing the risk of periodontal disease and caries. In the present study, denture hygiene instructions were delivered verbally following denture insertion. However, it is recommended that standardised oral hygiene instructions be clearly implemented and documented for all participants, as variations in oral hygiene practices may influence periodontal outcomes and act as a potential confounding factor. In a 6-year follow-up study, patients with well-designed RPDs who attended annual maintenance appointments had a low incidence of new caries lesions. Furthermore, regular periodontal maintenance every three to six months has been shown to support the longevity of abutment teeth in RPD wearers (Tada et al., 2015). Clinical evidence suggests that detrimental effects of RPDs on abutment teeth can be effectively managed with proper oral hygiene instruction and consistent dental check-ups, which significantly reduces the risk of both caries and periodontal disease (Yeung et al., 2000).

5.5.3 Patient Reported Outcome Using OHIP-14

Clinical examinations alone may not fully capture patients' experiences of comfort, confidence, or social function, which directly influence the success of RPD therapy. In addition to clinical outcomes, patient-reported OHRQoL was evaluated using OHIP-14. Validated instruments such as OHIP-14 are considered superior, as they provide structured, reliable, and comparable data across different studies (Saub et al., 2005).

The results of this study demonstrate that RPDs leads to a noticeable improvement in OHRQoL, irrespective of the framework material used. Both the PEEK and CoCr groups exhibited significant improvements across the majority of OHIP-14 domains, reinforcing the agreement that replacing missing teeth is vital for restoring physical function and psychological well-being especially if involving missing posterior teeth. Notably, CoCr exhibited broader and more consistent improvements particularly in functional limitation, physical pain, and disability domains; whereas

PEEK showed a stronger reduction in psychological disability, likely reflecting patients' favourable perceptions of its comfort and aesthetics.

The lack of statistically significant differences in OHRQoL outcomes between the PEEK and CoCr groups indicates that PEEK can be considered a clinically acceptable alternative to conventional CoCr frameworks. Our findings partly align with previous studies, although the literature remains limited and rather inconsistent. Mohamed and Rasha reported a clear patient preference for PEEK due to improved aesthetics and comfort, supporting our finding of psychological benefits (Mohamed & Rasha, 2019). In contrast, Hegazi et al. found no significant differences between PEEK and CoCr in terms of OHRQoL and satisfaction (Hegazi et al., 2025). These inconsistencies may be explained by methodological differences. Mohamed and Rasha used a short-term crossover design which may have increased sensitivity to patient-perceived differences, while Hegazi et al. employed a parallel-group design. Furthermore, variations in case selection, such as Hegazi et al.'s focus on Kennedy Class I patients compared with the unspecified Kennedy classification in Mohamed and Rasha's study, may also have influenced outcomes.

In our study, the questionnaire was administered at baseline and one month after denture insertion to evaluate the immediate effects of PEEK and CoCr RPDs. This short-term evaluation provided insight into patients' early adaptation, comfort, and overall satisfaction, complementing the clinical findings with a patient-centred dimension. Although OHIP assessments are commonly conducted after longer intervals typically at three months, six months, or one year (Ali et al., 2020; Hsu et al., 2021), our early evaluation aimed to capture the initial adjustment period. Previous study has reported that approximately 60% of experienced denture wearers are able to function satisfactorily within one week of receiving new dentures, whereas about 20% may require up to a month to achieve optimal adaptation (Farias-Neto & Carreiro, 2015). The marked improvement observed in this study may therefore represent patients' immediate satisfaction and relief upon regaining oral function and appearance, especially among those previously edentulous or dissatisfied with earlier prostheses.

Other studies used either non-validated or other questionnaire, further contributing to mixed results. Ge et al. reported no significant differences in patient satisfaction between PEEK and CoCr when assessed using a non-validated questionnaire, whereas Oliveira et al., using a visual analogue scale, found that PEEK

RPDs were associated with reduced masticatory performance and lower patient satisfaction compared with CoCr frameworks (Ge et al., 2025; Oliveira et al., 2025).

Nevertheless, despite the small sample size, the results of present study support the clinical effectiveness of both frameworks, with each material offering specific advantages. Although longer term studies with larger sample sizes are required to confirm these findings, the results suggest that PEEK frameworks, which are lighter and presumed to be more biocompatible, provide patient comfort comparable to that of well fitted metal frameworks. Consequently, PEEK may be recommended for patients who prioritize aesthetics or have metal sensitivities, with the expectation of achieving oral health related quality of life outcomes similar to those obtained with conventional metal frameworks.

5.5.3.1 Incidental Findings

Post-treatment maintenance findings highlighted the need for minor clasp adjustments during the early phase of use. At the one-week review, PEEK frameworks were generally reported as excessively tight, while some CoCr clasps exhibited initial looseness. The greater tightness perceived with PEEK clasps may be attributed to their material and design characteristics. Owing to PEEK's lower elastic modulus, increased clasp thickness, typically 1.0 to 1.5 mm, is required to achieve adequate retention (Lee et al., 2024; Zoidis et al., 2016; Tannous et al., 2012). In addition, PEEK can safely engage deeper undercuts, allowing closer adaptation to the tooth surface and improved retention without excessive stress on abutment teeth (Gray et al., 2021; El Mekawy & Elgamal, 2021).

A previous clinical study reported higher retention with CoCr frameworks than with PEEK; however, a uniform 0.25 mm undercut was applied to both materials, despite the manufacturer's recommendation of a 0.5 mm undercut for PEEK (Eldien 2020). The lack of detailed clasp design descriptions further limits interpretation, and this methodological approach may have underestimated the true retentive capacity of PEEK, which is better suited to deeper undercuts than rigid CoCr. Although in vitro studies suggest that maximum retention is achieved with PEEK clasps at a thickness of 1.5 mm and a 0.5 mm undercut, (Lee et al., 2024; Peng et al., 2020; Tannous et al., 2012), the present study employed thinner clasps (1.0-1.3 mm) while maintaining the same undercut depth. Despite this, patients consistently reported tightness at six months,

indicating that satisfactory clinical retention can be achieved even with reduced dimensions. However, this finding was based on patient perception, as no objective measurements of retentive forces were performed.

All adjustments were completed during the initial follow up, with no unscheduled visits required, suggesting that both PEEK and CoCr frameworks can be effectively managed with routine chairside modifications. These findings highlight a discrepancy between laboratory data and patient-reported outcomes and support the need for future studies integrating standardized mechanical testing with structured clinical evaluations. Recent systematic reviews and meta-analyses reporting comparable retention between CoCr clasps engaging 0.25 mm undercuts and PEEK clasps engaging 0.5 mm undercuts, which further support the clinical practicality of PEEK as an alternative clasp material (Soares et al., 2025).

Although PEEK generally exhibits superior colour stability compared with many other denture base materials, it is not entirely resistant to staining. Its semicrystalline structure, low water solubility, and minimal water absorption help limit discoloration but cannot fully prevent pigment adherence (Akl & Stendahl, 2022). In the present study, surface staining was observed in most PEEK frameworks at the six-month review, affecting 8 of 9 patients. Despite this aesthetic change, no associated periodontal or biological complications were detected during the same period.

These findings are consistent with previous reports indicating that, while PEEK exhibits better colour stability than conventional resins, it remains susceptible to staining from dietary chromogens such as coffee and tea (Papathanasiou et al., 2022; Polychronakis et al., 2020). A study by Erdağ et al. showed that colour changes following such exposure generally remain within clinically acceptable limits (Erdağ et al., 2023).

It is important to note that, apart from the present six-month review, no longitudinal clinical studies have specifically addressed staining of PEEK frameworks. The available evidence is limited to a few isolated reports. One case described severe dark staining after five years of service, attributed to the patient's use of highly pigmented traditional Chinese medicines (He et al., 2025). In contrast, Zoidis et al., reported a loss of surface gloss on PEEK RPD frameworks after one year, while Ichikawa et al. observed color and texture changes in PEEK clasps after two years (Ichikawa et al., 2019; Zoidis et al., 2016). These variations suggest that staining outcomes may be strongly influenced by patient-related factors and duration of service.

Interestingly, one participant in the present study exhibited almost no staining. Upon further questioning, the individual reported strict adherence to hygiene practices, including twice-daily brushing and monthly soaking in a cleansing solution, while consciously avoiding chromogenic foods. This observation aligns with previous findings that regular use of cleansers can mitigate long-term discoloration of PEEK (Polychronakis et al., 2020). While water immersion and thermal cycling alone do not produce clinically perceptible colour changes, age-related increases in surface roughness may enhance susceptibility to extrinsic staining over time (Porojan et al., 2021).

Current evidence suggests that both chemical and mechanical cleansing methods help maintain PEEK's surface integrity and aesthetic properties when performed correctly. Surface roughness generally remains below the plaque accumulation threshold, and colour changes are within clinically acceptable limits (Erdağ et al., 2023). Although standardized cleaning protocols for PEEK have not yet been established, conventional RPD hygiene recommendations, including gentle brushing, appropriate use of cleansers, and dietary counselling, appear sufficient. However, aggressive professional cleaning techniques such as air polishing should be avoided, as they may increase surface roughness and promote plaque retention.

5.6 Discussion on Correlation of FEA and Clinical Study

The FEA provided insights into the stress distribution and deformation patterns of the PEEK and CoCr RPD frameworks. Although CoCr demonstrated slightly higher VMS values, the overall deformation patterns between the two materials were comparable. Clinically, this corresponded with the negligible changes in abutment tooth mobility recorded over six months, suggesting that both frameworks exerted stresses within physiologically acceptable limits. This alignment suggests that FEA can reliably model PDL behaviour under functional loading, particularly for short-term evaluation of abutment stress.

FEA also revealed distinct material-specific responses: PEEK exhibited greater deformation with lower stress concentration, whereas CoCr showed the opposite pattern, which is limited deformation but higher stress concentration. Despite the predicted stresses, no clinical framework failure, such as a rest fracture or clasp distortion, was observed over six months. This indicates that FEA, while conservative

in predicting potential high-stress regions, may slightly overestimate the risk of material failure under controlled clinical conditions. Factors such as the short duration of clinical follow-up or patient factors could explain this discrepancy. Additionally, patient-reported outcomes using OHIP-14 showed comparable improvements in OHQoL for both PEEK and CoCr frameworks, supporting the fact that mechanical behaviour predicted by FEA translates into satisfactory clinical performance.

However, occlusion may have influenced the clinical outcomes observed. While the FEA model applied a standardized static load of 120 N, the clinical study involved participants with varying opposing dentitions, including complete dentures, removable partial dentures, and fully dentate arches. These occlusal conditions can significantly affect both the magnitude and distribution of load transmitted to the abutment teeth and supporting mucosa. For instance, complete dentures generally produce lower bite forces, whereas fully dentate arches generate higher and more concentrated loads. Such variability is not fully captured in FEA models, which assume simplified loading conditions, and may partly explain the discrepancy between the predicted stress patterns and the relatively stable clinical findings observed over six months. Furthermore, in cases involving mandibular removable prostheses, the denture base may act as a limiting factor, as excessive occlusal loading can induce mucosal discomfort and denture instability, thereby restricting the functional bite force even against fully dentate opposing arches.

Nevertheless, the present study illustrates the complementary value of FEA and clinical evaluation. FEA provides detailed insights into stress distribution and potential weak points in the prosthesis, guiding design optimization and material selection, while clinical observation validates whether these predictions manifest under *in vivo* conditions. The close agreement between predicted and observed outcomes reinforces the predictive validity of FEA for RPD design, particularly in assessing the risk to abutment teeth and framework integrity.

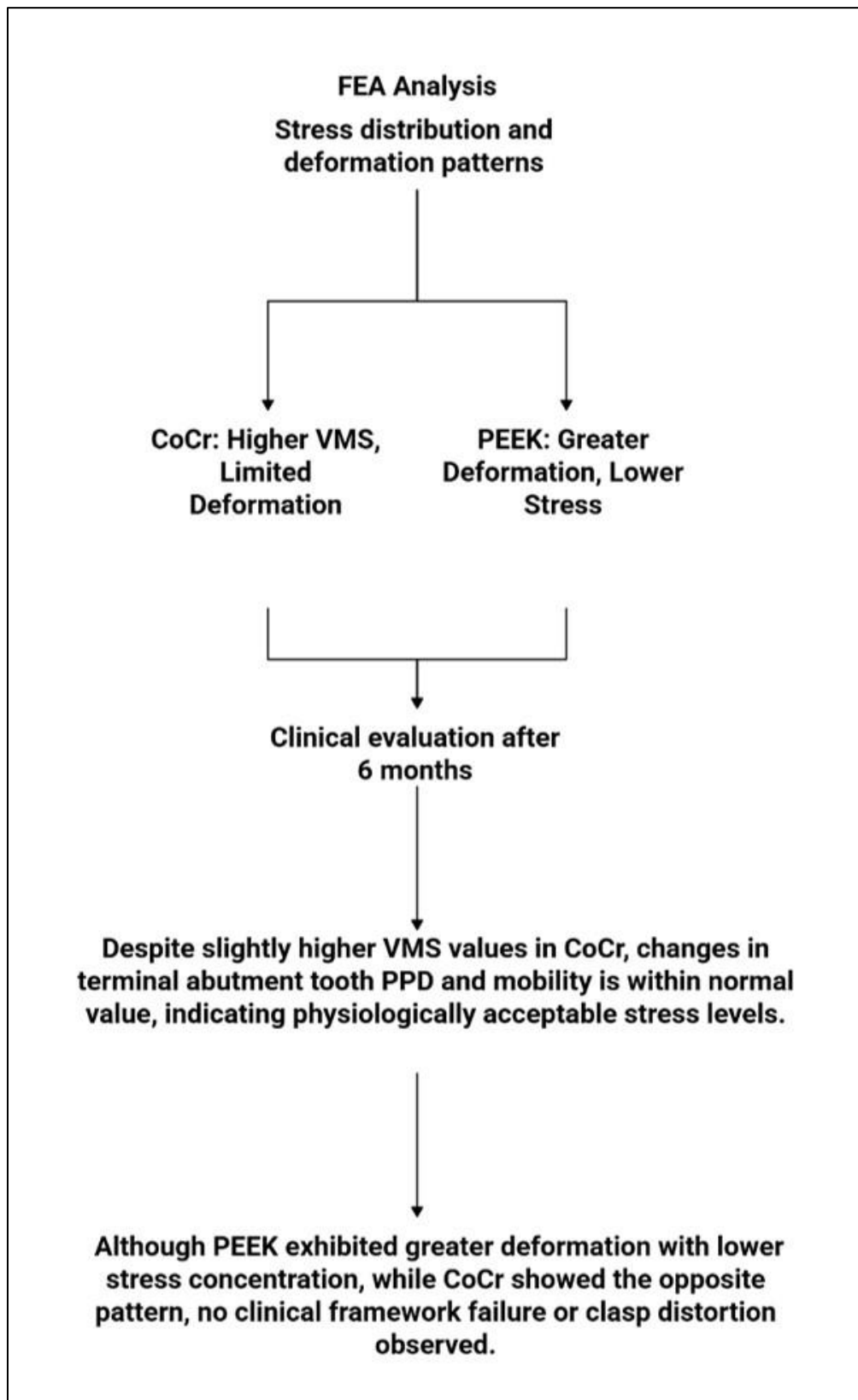


Figure 5.1 Summary the Correlation of FEA and Clinical Study

5.7 Cost of PEEK versus CoCr RPD

In terms of cost per arch, the PEEK framework (RM 980) is substantially more expensive than the CoCr framework (RM 250), resulting in total treatment costs of RM 1,360 and RM 630, respectively. Since the laboratory and processing charges are identical for both materials (RM 200 and RM 180), the difference of RM 730 arises solely from the framework, making PEEK more than twice as costly as CoCr. The cost distribution further emphasizes this contrast: in PEEK prostheses, the framework accounts for the majority of total expenditure (72%), whereas in CoCr prostheses costs are more evenly distributed among laboratory, framework, and processing components.

When considering cost-effectiveness, however, the decision to use PEEK should not be based on financial factors alone but also on potential patient-centred benefits. PEEK frameworks offer clinical advantages such as increased retention, superior aesthetics, reduced weight, lower thermal conductivity, and enhanced biocompatibility, which may translate into improved comfort and overall acceptance (Akl & Stendahl, 2022; Khurshid et al., 2022). These attributes may justify the additional expense in selected cases, particularly in patients with metal sensitivity, high aesthetic demands, or clinical conditions where a lighter framework could reduce functional stress. For routine situations where these considerations are less critical, CoCr remains the more practical and cost-effective option due to its proven durability, affordability, and long-established clinical success.

5.8 Limitations of the Study

This study has several limitations that should be acknowledged. For the FEA study, biological tissues such as teeth, mucosa, and bone were modelled as homogeneous, isotropic, and linearly elastic materials, which does not fully replicate their complex anisotropic and viscoelastic behavior. Additionally, loading conditions were simplified to static forces and may not reflect the variability of dynamic masticatory function. The validated baseline stress thresholds and experimental validation using physical models were not incorporated; therefore, the findings should be interpreted as relative comparisons rather than absolute clinical values.

For the clinical study, the sample size, though comparable to prior PEEK RPD studies, was limited by strict inclusion criteria requiring good baseline periodontal

health. Ultimately, 16 abutment teeth in the PEEK group and 12 in the CoCr group were evaluated. While sufficient for comparative analysis, a larger sample would improve generalizability. Patient recruitment, retention, and follow-up posed additional challenges, particularly because many RPD wearers are elderly. Age-related health complications affected participation and long-term follow-up, leading to scheduling difficulties or study withdrawal. In the CoCr group, two participants withdrew after recruitment and one after the one-month review due to health issues. These attrition factors reduced the final sample size and may have affected statistical power, though numbers remained near the calculated requirement.

Clinical observations were limited to six months, which may not capture long-term fatigue, wear, or biological responses of the periodontal ligament and supporting structures. A longer follow-up, ideally 2 to 5 years, is recommended to better evaluate clinical and periodontal outcomes. Finally, as the study included participants with relatively good oral and systemic health, the findings may not be fully generalizable to the broader RPD population, many of whom may have compromised health or less favourable oral conditions.

CHAPTER 6

CONCLUSION

6.1 Introduction

Within the limitations of this study, the following conclusions may be drawn:

- i. CoCr frameworks are recommended for Kennedy Class I cases with good to moderate periodontal support, with bar designs preferred for lower PDL stress and plate designs reserved for patients with strong abutments, while PEEK frameworks showed gentler stress transmission to the PDL and mucosa but higher internal framework stress, indicating suitability for metal sensitive patients and the need for design reinforcement in distal extension cases.
- ii. The choice of rest position should be individualized based on the patient's periodontal and residual ridge condition, as well as long-term biological considerations. Mesial rests were particularly advantageous for PEEK frameworks by minimizing deformation and internal stress. For distal rests offered greater protection for abutments by reducing PDL stress, except in CoCr bar.
- iii. Both PEEK and CoCr frameworks demonstrated comparable periodontal outcomes for terminal abutment teeth, with no significant differences observed over a six-month observation period.
- iv. Both PEEK and CoCr RPD frameworks significantly improved OHQoL, with no significant differences between materials, supporting PEEK as a clinically acceptable alternative to CoCr frameworks from the patient's perspective.
- v. FEA predicted distinct biomechanical behaviours for PEEK and CoCr frameworks; however, these differences did not translate into clinically detectable differences in abutment tooth stability or framework integrity during the six-month observation period.

6.2 Clinical Recommendations

Clinically, PEEK RPDs can provide satisfactory retention when designed with a 0.5 mm undercut, conventional CoCr-type rest seat dimensions, a clasp width and thickness of minimum 1.0 to 1.3 mm, and a uniform lingual plate thickness of 1.3 mm that extends vertically to cover the lingual surfaces of the anterior teeth. These design parameters are based on the current clinical observations over a six-month period and available laboratory and manufacturer recommendations.

As PEEK frameworks have been reported to develop surface staining within six months, and as observed within the short-term follow-up of the present study, limiting exposure to dietary staining factors and maintaining meticulous oral hygiene are advisable. Daily brushing combined with monthly use of denture-cleaning tablets may help reduce discoloration during the early period. Regular professional polishing at follow-up visits, along with reinforcement of oral hygiene instructions, is also recommended. However, the long-term effectiveness of maintenance strategies beyond a six-month period remains to be established and warrants further investigation.

6.3 Novelty of the Study

The novelty of this study lies in three key aspects. First, it evaluates the biomechanical influence of connector design and rest position specifically in the context of distal extension cases, providing more focused insight into stress distribution patterns. Second, the clinical study applies strict standardization, including restriction to lower Kennedy Class I, consistent abutment type, and uniform denture design, which reduces variability compared to previous studies. Third, the integration of finite element analysis with clinical outcomes allows both mechanical behaviours and biological response to be assessed together, providing a more comprehensive evaluation than studies using either approach alone.

6.4 Future Perspectives and Recommendations

In biomechanical studies, the possibilities are numerous and should include various clinical scenarios and design variations. In particular, future FEA could explore

the use of different retentive and supportive components, such as circumferential clasps, I-bars, and precision attachments, when incorporated into flexible PEEK frameworks compared with rigid CoCr frameworks. In parallel, the influence of varying levels of periodontal bone support of abutment teeth, for example, normal versus reduced bone height, should be evaluated, as these conditions are frequently encountered in clinical practice and may substantially affect stress distribution and displacement patterns.

Moreover, in the absence of empirical optimisation data specific to PEEK, the RPD design adopted in the present study was based primarily on laboratory guidelines and manufacturer recommendations rather than material-specific biomechanical optimisation. Future research should therefore include comprehensive finite element and in vitro investigations assessing the biomechanical performance of PEEK major connectors with systematically varied heights, widths, and reinforcement configurations. Such studies are necessary to establish evidence-based design parameters tailored specifically to PEEK as a framework material.

From a clinical perspective, future investigations should build upon the current pilot study by increasing both the sample size and the duration of follow-up. While the present trial with 17 participants provides valuable preliminary insights, it remains underpowered for definitive conclusions and is limited to short- to mid-term outcomes. The reliability of the results will be strengthened by continuous recruitment of participants in order to achieve a sufficiently powered cohort (e.g., 25–30 participants per group). It is equally important to follow up with the current cohort over an extended period of time, ideally five to ten years, to capture the true clinical performance of PEEK and CoCr RPD frameworks. Such longitudinal data would enable a comprehensive evaluation of abutment tooth survivability, periodontal health, and prosthetic complications, as well as the long-term cost-effectiveness of each material which provides stronger evidence to guide clinical decision-making in the selection of RPD materials.

In addition to extending the current study, future trials should also address new clinical questions through targeted RCTs. One promising direction is to evaluate different Kennedy classification scenarios or to integrate adjunctive approaches, such as implant-assisted RPDs, which directly integrate biomechanical considerations with clinical practice. Furthermore, incorporating microbiological analyses of plaque samples around abutment teeth could clarify whether framework material influences the

periodontal microbiome, potentially explaining mechanisms underlying any observed differences in periodontal health.

REFERENCES

- Ahmad, R., Chen, J., Abu-Hassan, M. I., Li, Q., & Swain, M. V. (2015). Investigation of mucosa-induced residual ridge resorption under implant-retained overdentures and complete dentures in the mandible. *International Journal of Oral & Maxillofacial Implants*, 30(3). DOI: 10.11607/jomi.3844
- Ahmed, N., Abbasi, M. S., Haider, S., Ahmed, N., Habib, S. R., Altamash, S., Alam, M. K. (2021). Fit accuracy of removable partial denture frameworks fabricated with CAD/CAM, rapid prototyping, and conventional techniques: A systematic review. *BioMed Research International*, 1-11. <https://doi.org/10.1155/2021/3194433>.
- Akaltan, F., & Kaynak, D. (2005). An evaluation of the effects of two distal extension removable partial denture designs on tooth stabilization and periodontal health. *Journal of Oral Rehabilitation*, 32(11), 823-829. <https://doi.org/10.1111/j.1365-2842.2005.01511.x>
- Akl, M. A., & Stendahl, C. G. (2022). Removable partial denture frameworks in the age of digital dentistry: a review of the literature. *Prosthesis*, 4(2), 184-201. <https://doi.org/10.3390/prosthesis4020019>
- Al Jabbari, Y. S. (2014). Physico-mechanical properties and prosthodontic applications of Co-Cr dental alloys: a review of the literature. *The Journal of Advanced Prosthodontics*, 6(2), 138-145. <https://doi.org/10.4047/jap.2014.6.2.138>
- Alqutaibi, A. Y., Alghauli, M. A., Algabri, R. S., Hamadallah, H. H., Aboalrejal, A. N., Zafar, M. S., & Fareed, M. A. (2025). Applications, modifications, and manufacturing of polyetheretherketone (PEEK) in dental implantology: A comprehensive critical review. *International Materials Reviews*, 70(2), 103-136. <https://doi.org/10.1177/09506608251314251>
- Alexakou, E., Damanaki, M., Zoidis, P., Bakiri, E., Mouzis, N., Smidt, G., & Kourtis, S. (2019). PEEK high performance polymers: A review of properties and clinical applications in prosthodontics and restorative dentistry. *European Journal of Prosthodontics and Restorative Dentistry*, 27, 113-121. doi: 10.1922/EJPRD_01892Zoidis09
- Alghazzawi, T. F. (2016). Advancements in CAD/CAM technology: Options for practical implementation. *Journal of Prosthodontic Research*, 60(2), 72-84. <https://doi.org/10.1016/j.jpor.2016.01.003>

- Ali, I. E., Tanikawa, C., Chikai, M., Ino, S., Sumita, Y., & Wakabayashi, N. (2023). Applications and performance of artificial intelligence models in removable prosthodontics: A literature review. *Journal of Prosthodontic Research*, 68(3), 358-367. https://doi.org/10.2186/jpr.JPR_D_23_00073
- Ali, Z., Baker, S., Sereno, N., & Martin, N. (2020). A pilot randomized controlled crossover trial comparing early OHRQoL outcomes of cobalt-chromium versus PEEK removable partial denture frameworks. *The International Journal of Prosthodontics*, 33(4), 386-392. DOI: 10.11607/ijp.6604
- Aoda, K., Shimamura, I., Tahara, Y., & Sakurai, K. (2010). Retainer design for unilateral extension base partial removable dental prosthesis by three-dimensional finite element analysis. *Journal of Prosthodontic Research*, 54(2), 84-91. <https://doi.org/10.1016/j.jpor.2009.11.005>
- Arnold, C., Hey, J., Schweyen, R., & Setz, J. M. (2018). Accuracy of CAD-CAM-fabricated removable partial dentures. *The Journal of Prosthetic Dentistry*, 119(4), 586-592. <https://doi.org/10.1016/j.prosdent.2017.04.017>
- Ayaz, E., & Ustun, S. (2020). Effect of staining and denture cleaning on color stability of differently polymerized denture base acrylic resins. *Nigerian Journal of Clinical Practice*, 23(3), 304-309. DOI: 10.4103/njcp.njcp_330_19
- Ben-Ur, Z., Mijiritsky, E., Gorfil, C., & Brosh, T. (1999). Stiffness of different designs and cross-sections of maxillary and mandibular major connectors of removable partial dentures. *The Journal of Prosthetic Dentistry*, 81(5), 526-532. [https://doi.org/10.1016/S0022-3913\(99\)70206-4](https://doi.org/10.1016/S0022-3913(99)70206-4)
- Bhojaraju, N., Srilakshmi, J., & Vishwanath, G. (2014). Study of deflections in maxillary major connectors: a finite element analysis. *The Journal of Indian Prosthodontic Society*, 14, 50-60. <https://doi.org/10.1007/s13191-012-0237-3>
- Bradfield, C., Sykes, L. M., Mmutlana, T. I., & Warren, N. (2025). A comparison of the flexibility and fracture point of cast cobalt-chromium, milled cobalt-chromium, laser printed cobalt-chromium and milled Polyetherketoneketone partial denture clasps. *South African Dental Journal*, 80(1), 20-28. <https://doi.org/10.17159/sadj.v80i01.20361>
- Budtz-Jørgensen, E., & Isidor, F. (1990). A 5-year longitudinal study of cantilevered fixed partial dentures compared with removable partial dentures in a geriatric population. *The Journal of Prosthetic Dentistry*, 64(1), 42-47. [https://doi.org/10.1016/0022-3913\(90\)90151-2](https://doi.org/10.1016/0022-3913(90)90151-2)

- Bural Alan, C. (2024). Biomechanics of Removable Partial Dentures. In *Removable Partial Dentures: A Practitioners' Manual* (pp. 29-40): Cham: Springer International Publishing.
- Campbell, S. D., Cooper, L., Craddock, H., Hyde, T. P., Nattress, B., Pavitt, S. H., & Seymour, D. W. (2017). Removable partial dentures: The clinical need for innovation. *The Journal of Prosthetic Dentistry*, 118(3), 273-280. <https://doi.org/10.1016/j.prosdent.2017.01.008>
- Carr, A. B., & Brown, D. T. (2010). *McCracken's removable partial prosthodontics-e-book*: Elsevier Health Sciences.
- Carra, M. C., Detzen, L., Kitzmann, J., Woelber, J. P., Ramseier, C. A., & Bouchard, P. (2020). Promoting behavioural changes to improve oral hygiene in patients with periodontal diseases: A systematic review. *Journal of Clinical Periodontology*, 47, 72-89. <https://doi.org/10.1111/jcpe.13234>Digital Object Identifier (DOI)
- Chaturvedi, S., M Alqahtani, N., A Al-Qarni, M., M Alqahtani, S., Suleman, G., Yaqoob, A., Chaturvedi, M. (2024). Evaluation of the methods for determining accuracy of fit and precision of RPD framework in digital (3D printed, milled) and conventional RPDs: A systematic review. *BMC oral health*, 24(1), 1-14. <https://doi.org/10.1186/s12903-024-05262-x>
- Chen, X., Mao, B., Zhu, Z., Yu, J., Lu, Y., Zhang, Q., Yu, H. (2019). A three-dimensional finite element analysis of mechanical function for 4 removable partial denture designs with 3 framework materials: CoCr, Ti-6Al-4V alloy and PEEK. *Scientific reports*, 9(1), 1-10. <https://doi.org/10.1038/s41598-019-50363-1>
- Craig, R., & Powers, J. (2002). Restorative dental materials, 11th edn, St. Louis: Mosby, 348-370.
- Curinga, M. R. S., da Silva, G. G., Pereira, A. L. C., de Freitas, R. F. C. P., & Carreiro, A. D. F. P. (2023a). Fabrication of a removable partial denture of injectable poly (ether-ether-ketone)(PEEK) made partially by a digital workflow: case report. *Brazilian Journal of Health Review*, 6(1), 4027-4039. <https://doi.org/10.34119/bjhrv6n1-312>
- Curinga, M. R. S., Ribeiro, A. K. C., de Moraes, S. L. D., do Egito Vasconcelos, B. C., Carreiro, A. d. F. P., & Pellizzer, E. P. (2023b). Mechanical properties and accuracy of removable partial denture frameworks fabricated by digital and

- conventional techniques: A systematic review. *The Journal of Prosthetic Dentistry*. DOI: 10.1016/j.prosdent.2023.01.032
- Dakhli, R., Aguir, S., Rzigui, S., Mansour, L., Nasri, S., & Nouira, Z. (2023). Polyetherether-Ketone (PEEK) Kennedy class III removable partial dentures: A case report. *Open Access Journal of Dental Sciences*, 8(2), 1-7.
- Dula, L.J., Ahmed, E., Krasniqi, Z., & Shala, K. (2015). Clinical Evaluation of Removable Partial Dentures on the Periodontal Health of Abutment Teeth: A Retrospective Study. *The Open Dentistry Journal*, 9, 132-139. 10.2174/1874210601509010132
- Dula, L. J., Shala, K. S., Pustina-Krasniqi, T., Bicaj, T., & Ahmed, E. F. (2015). The influence of removable partial dentures on the periodontal health of abutment and non-abutment teeth. *European Journal of Dentistry*, 9(03), 382-386. 10.4103/1305-7456.163234. DOI: 10.4103/1305-7456.163234
- El Mekawy, N., & Elgamal, M. (2021). Retention assessment of high performance polyetheretherketone removable partial denture frameworks constructed by various techniques (in vitro study). *Journal of Dentistry*, 22(4), 281. 10.30476/DENTJODS.2021.87488.1265
- Eldien, A. R. A. S. (2020). *Polyetherether Ketone (PEEK) versus Metallic Kennedy Class III Removable Partial Dentures: Evaluation of Retention Force*. [Master dissertation, Mansoura University Mansoura, Egypt]. ProQuest Dissertations and Theses Global.
- Elsayed, S., Sherief, D. I., Selim, M. M., & Alian, G. A. (2022). Strength of Polyether Ether Ketone Composite as a Major Connector Material for Removable Partial Dentures. *Open Access Macedonian Journal of Medical Sciences*, 10(D), 229-237. <https://orcid.org/0000-0001-6497-5446>
- Erdağ, Ü. H., Şahin, O., Köroğlu, A., Özdemir, T., & Dede, D. Ö. (2023). Performance of polyether ether ketone (peek) for dental applications: surface roughness and color stability. *Polymer Bulletin*, 80(6), 6819-6834. <https://doi.org/10.1007/s00289-022-04393-x>
- Farias-Neto, A., & Carreiro, A. (2015). Changes in patient satisfaction and masticatory efficiency during adaptation to new dentures. *Compendium of Continuing Education in Dentistry*, 36(3), 174-177.
- Fill, T. S., Toogood, R. W., Major, P. W., & Carey, J. P. (2012). Analytically determined mechanical properties of, and models for the periodontal ligament:

- critical review of literature. *Journal of Biomechanics*, 45(1), 9-16.
<https://doi.org/10.1016/j.jbiomech.2011.09.020>
- Ge, Y., Zhao, T., Fan, S., Liu, P., & Liu, X. (2025). A completely digital workflow for PEEK removable partial dentures: A preliminary clinical study. *The Journal of Prosthetic Dentistry*.134 (3): 791.e1-791.e8.
<https://doi.org/10.1016/j.prosdent.2025.05.028>
- Gentz, F. I., Brooks, D. I., Liacouras, P. C., Petrich, A., Hamlin, C. M., Ellert, D. O., & Ye, L. (2022). Retentive forces of removable partial denture clasp assemblies made from polyaryletherketone and cobalt-chromium: A comparative study. *Journal of Prosthodontics*, 31(4), 299-304. <https://doi.org/10.1111/jopr.13398>
- Gray, D., Barraclough, O., Ali, Z., & Nattress, B. (2021). Modern partial dentures-part 2: A review of novel metal-free materials and innovations in polymers. *British Dental Journal*, 230(12), 813-818. <https://doi.org/10.1038/s41415-021-3068-y>
- Güteryüz, A., Korkmaz, C., Şener, A., & Taş, M. O. (2021). The effect of thermo-mechanical fatigue on the retentive force and dimensional changes in polyetheretherketone clasps with different thickness and undercut. *The Journal of Advanced Prosthodontics*, 13(5), 304. doi: 10.4047/jap.2021.13.5.304
- Guo, F., Huang, S., Liu, N., Hu, M., Shi, C., Li, D., & Liu, C. (2022). Evaluation of the mechanical properties and fit of 3D-printed polyetheretherketone removable partial dentures. *Dental Materials Journal*. <https://doi.org/10.4012/dmj.2022-063>
- Haleem, A., & Javaid, M. (2019). Polyether ether ketone (PEEK) and its manufacturing of customised 3D printed dentistry parts using additive manufacturing. *Clinical Epidemiology and Global Health*, 7(4), 654-660.
<https://doi.org/10.1016/j.cegh.2019.03.001>
- Hallikerimath, R., Mallikarjun, H. D., Patil, V., & Kumar, V. S. (2015). Evaluation of deflection in single palatal strap major connector as influenced by different shapes of palatal vault: a three-dimensional finite element study. *Journal of International Oral Health*, 7(10), 53.
- Hamid, N. F. A., Ahmad, R., Ariffiin, F., & Shuib, S. (2024). Science mapping of research clusters and core research areas in removable partial dentures. *Journal of Health and Translational Medicine* 9-15.
- Hamid, N. F. A., Ariffin, F., Adam, F. A., Shuib, S., & Ahmad, R. (2025). Evolving research on periodontal health of abutment teeth in removable partial dentures:

- A Scopus-based bibliometric analysis. *Journal of Indian Society of Periodontology*, 29(1), 6-13. 10.4103/jisp.jisp_437_24
- Hamid, N. F. A., Ariffin, F., & Ahmad, R. (2023). A Bibliometric Analysis of Removable Partial Denture-related Research in Dentistry. *Archives of Orofacial Sciences*(2). DOI: 10.21315/aos2023.1802.RV03
- Hamid, N. F. A., Yacob, N., Shuib, S., & Ahmad, R. (2025). Digital fabrication of flanges in removable partial dentures: a step-by-step workflow. *IIUM Journal of Orofacial and Health Sciences*, 6(1), 141-146. DOI: <https://doi.org/10.31436/ijohs.v6i1.305>
- Harb, I. E., Abdel-Khalek, E. A., & Hegazy, S. A. (2019). CAD/CAM constructed poly(etheretherketone) (PEEK) framework of kennedy class I removable partial denture: A clinical report. *Journal of Prosthodontics*, 28(2), e595-e598. doi:10.1111/jopr.12968
- He, Z., Wu, Q., Zhang, N., Yang, X., Lu, Y., Yan, P., Yu, H. (2025). A digital chairside repair protocol for removable partial dentures with polyetheretherketone frameworks. *The Journal of Prosthetic Dentistry*, 133(5), 1122-1126. <https://doi.org/10.1016/j.prosdent.2023.07.017>
- Hegazi, H. M., Elkhadem, A., Fayyad, A., Elkady, D. M., Elkerdawy, M. W., & Sedky, A. (2025). Patient-centered outcomes of indirect CAD-CAM removable partial denture frameworks: A 2-year follow-up study. *Journal of Prosthodontics*, 34(8), 818-826. <https://doi.org/10.1111/jopr.14100>
- Heimer, S., Schmidlin, P. R., & Stawarczyk, B. (2017). Discoloration of PMMA, composite, and PEEK. *Clinical Oral Investigations*, 21, 1191-1200. <https://doi.org/10.1007/s00784-016-1892-2>
- Hemming, K., Taljaard, M., Weijer, C., & Forbes, A. B. (2020). Use of multiple period, cluster randomised, crossover trial designs for comparative effectiveness research. *BMJ*, 371. doi: <https://doi.org/10.1136/bmj.m3800>
- Hsu, Y.J., Lin, J.R., & Hsu, J.F. (2021). Patient satisfaction, clinical outcomes and oral health-related quality of life after treatment with traditional and modified protocols for complete dentures. *Journal of Dental Sciences*, 16(1), 236-240. <https://doi.org/10.1016/j.jds.2020.05.024>
- Htun, P. L., Kyaw, P. P., Nyan, M., Win, A., & Tint, K. (2020). Innovation of removable partial denture with esthetic clasp assembly: A Case Report. *Journal of Clinical Dentistry and Related Research*, 1-5

- Hussein, M. O. (2022). Performance of Graphene-Based and Polyether-Ether-Ketone Polymers as Removable Partial Denture Esthetic Clasp Materials after Cyclic Fatigue. *Polymers*, 14(15), 2987. <https://doi.org/10.3390/polym14152987>
- Ichikawa, T., Kurahashi, K., Liu, L., Matsuda, T., & Ishida, Y. (2019). Use of a polyetheretherketone clasp retainer for removable partial denture: a case report. *Dentistry journal*, 7(1), 4. <https://doi.org/10.3390/dj7010004>
- Igarashi, Y., Ogata, A., Kuroiwa, A., & Wang, C. (1999). Stress distribution and abutment tooth mobility of distal-extension removable partial dentures with different retainers: an in vivo study. *Journal of Oral Rehabilitation*, 26(2), 111-116. <https://doi.org/10.1046/j.1365-2842.1999.00345.x>
- Iosif, L., Țăncu, A. M. C., Amza, O. E., Gheorghe, G. F., Dimitriu, B., & Imre, M. (2024). AI in prosthodontics: a narrative review bridging established knowledge and innovation gaps across regions and emerging frontiers. *Prosthesis*, 6(6), 1281-1299. <https://doi.org/10.3390/prosthesis6060092>
- Iwaki, M., Akiyama, Y., Qi, K., Sahaprom, N., Kohri, K., Masumoto, M., . . . Shinpo, H. (2024). Oral health-related quality of life and patient satisfaction using three-dimensional printed dentures: A crossover randomized controlled trial. *Journal of Dentistry*, 150, 105338. <https://doi.org/10.1016/j.jdent.2024.105338>
- Jantaban, N., Suriyawanakul, J., Sae-Lee, D., Rungsiyakull, P., & Poovarodom, P. (2025). Biomechanical comparison of cobalt-chromium and PEEK frameworks in distal-extension removable partial dentures using finite element analysis. *Journal of International Dental and Medical Research*, 18(2), 599-609.
- Jassim, N. A., & Jaber, M. A. R. (2019). Evaluation of the effect of different surface treatments on bond strength of heat cured acrylic resin at Co-Cr Alloy and PEEK polymer interface. *International Journal of Medical Research & Health Sciences*, 8(1), 71-83.
- Jiao, T., Chang, T., & Caputo, A. (2009). Load transfer characteristics of unilateral distal extension removable partial dentures with polyacetal resin supporting components. *Australian Dental Journal*, 54(1), 31-37. <https://doi.org/10.1111/j.1834-7819.2008.01085.x>
- Juvora Ltd. (2022). JUVORA™ dental disc processing & technique guide [PDF]. Inivbio.https://inivbio.com/-/media/downloads/inivbio/eifu---processing-guides/processing-guide_rev-13_fda_usa.pdf

- Kanbara, R., Nakamura, Y., Ochiai, K. T., Kawai, T., & Tanaka, Y. (2012). Three-dimensional finite element stress analysis: the technique and methodology of non-linear property simulation and soft tissue loading behavior for different partial denture designs. *Dental Materials Journal*, 31(2), 297-308. <https://doi.org/10.4012/dmj.2011-165>
- Kapur, K. K., Deupree, R., Dent, R. J., & Hasse, A. L. (1994). A randomized clinical trial of two basic removable partial denture designs. Part I: Comparisons of five-year success rates and periodontal health. *The Journal of Prosthetic Dentistry*, 72(3), 268-282. [https://doi.org/10.1016/0022-3913\(94\)90340-9](https://doi.org/10.1016/0022-3913(94)90340-9)
- Kern, M., & Wagner, B. (2001). Periodontal findings in patients 10 years after insertion of removable partial dentures. *Journal of Oral Rehabilitation*, 28, 991-997. <https://doi.org/10.1111/j.1365-2842.2001.00788.x>
- Khurshid, Z., Nedumgottil, B. M., Ali, R. M. M., Bencharit, S., & Najeeb, S. (2022). Insufficient Evidence to ascertain the long-term survival of peek dental prostheses: A systematic review of clinical studies. *Polymers*, 14(12), 2441. <https://doi.org/10.3390/polym14122441>
- Kibi, M., Ono, T., Dong, J., Mitta, K., Gonda, T., & Maeda, Y. (2009). Development of an RPD CAD system with finite element stress analysis. *Journal of Oral Rehabilitation*, 36(6), 442-450. DOI:10.1111/j.1365-2842.2009.01949.x
- Knezović Z. D., Čelebić, A., & Valentić-Peruzović, M. (2002). The effect of removable partial dentures on periodontal health of abutment and non-abutment teeth. *Journal of Periodontology*, 73(2), 137-144. <https://doi.org/10.1902/jop.2002.73.2.137>
- Knight, E. T., Liu, J., Seymour, G. J., Faggion Jr, C. M., & Cullinan, M. P. (2016). Risk factors that may modify the innate and adaptive immune responses in periodontal diseases. *Periodontology* 2000, 71(1), 22-51. <https://doi.org/10.1111/prd.12110>
- Ko, C. C., Rocha, E. P., & Larson, M. (2012). Past, present and future of finite element analysis in dentistry. *Finite Element Analysis-From Biomedical Applications to Industrial Developments*, 1-25.
- Kouhi, M., de Souza Araújo, I. J., Asa'ad, F., Zeenat, L., Bojedla, S. S. R., Pati, F., Bodaghi, M. (2024). Recent advances in additive manufacturing of patient-specific devices for dental and maxillofacial rehabilitation. *Dental Materials*. 40(4), 700-715. <https://doi.org/10.1016/j.dental.2024.02.006>

- Kurahashi, K., Matsuda, T., Ishida, Y., & Ichikawa, T. (2019). Effect of surface treatments on shear bond strength of polyetheretherketone to autopolymerizing resin. *Dentistry Journal*, 7(3), 82. <https://doi.org/10.3390/dj7030082>
- Kurtz, S. M., & Devine, J. N. (2007). PEEK biomaterials in trauma, orthopedic, and spinal implants. *Biomaterials*, 28(32), 4845-4869. <https://doi.org/10.1016/j.biomaterials.2007.07.013>
- Lee, W.F., Chen, M. S., Peng, T.Y., Huang, P. C., Nikawa, H., & Peng, P.W. (2024). Comparative analysis of the retention force and deformation of PEEK and PEKK removable partial denture clasps with different thicknesses and undercut depths. *The Journal of Prosthetic Dentistry*, 131(2), 291. e291-291. e299. <https://doi.org/10.1016/j.prosdent.2023.09.042>
- Lim, C.Y., & In, J. (2021). Considerations for crossover design in clinical study. *Korean Journal of Anesthesiology*, 74(4), 293-299. <https://doi.org/10.4097/kja.21165>
- Lo Russo, L., Chochlidakis, K., Caradonna, G., Molinelli, F., Guida, L., & Ercoli, C. (2022). Removable partial dentures with polyetheretherketone framework: The influence on residual ridge stability. *Journal of Prosthodontics*, 31(4), 333-340. <https://doi.org/10.1111/jopr.13408>
- Luemkemann, N., Eichberger, M., Murphy, R. J., & Stawarczyk, B. (2020). Suitability of the new Aryl-Ketone-Polymer indicated for removable partial dentures: Analysis of elastic properties and bond strength to denture resin. *Dental Materials Journal*, 39(4), 539-546. <https://doi.org/10.4012/dmj.2019-125>
- Lyu, H., Murakami, N., Yamazaki, T., Wada, J., Utsumi, M., & Wakabayashi, N. (2023). Evaluation of PEEK and zirconia occlusal rest designs for removable partial dentures based on finite element analysis. *Journal of Prosthodontic Research*, 67(2): 196–205. DOI: https://doi.org/10.2186/jpr.JPR_D_22_00011
- Mansour, A. S., Abbas, N. A., & Cheta, N. (2020). Evaluation of Candida Albicans growth on Bre-flex versus PEEK denture base in bilateral maxillary bounded partial denture: A randomized clinical trial. *Advanced Dental Journal*, 2(4), 177-183. DOI: 10.21608/adjc.2020.24098.1055
- Maraka, N., & Alaa'a Salloum, M. A. (2021). Comparative study between removable partial dentures frameworks fabricated using PEEK and using Co-Cr alloy: clinical study. *Teikyo Medical Journal*, 44(6), 2685-2692.
- Marie, A., Keeling, A., Hyde, T. P., Nattress, B. R., Pavitt, S., Murphy, R. J., Wood, D. J. (2019). Deformation and retentive force following in vitro cyclic fatigue of

- cobalt-chrome and aryl ketone polymer (AKP) clasps. *Dental Materials*, 35(6), e113-e121. <https://doi.org/10.1016/j.dental.2019.02.028>
- Mayinger, F., Micovic, D., Schleich, A., Roos, M., Eichberger, M., & Stawarczyk, B. (2021). Retention force of polyetheretherketone and cobalt-chrome-molybdenum removable dental prosthesis clasps after artificial aging. *Clinical Oral Investigations*, 25, 3141-3149. <https://doi.org/10.1007/s00784-020-036425>
- McCracken, W. L. (2004). Contemporary partial denture designs. *Journal of Prosthetic Dentistry*, 92(5), 409-417. [10.1016/j.prosdent.2004.08.001](https://doi.org/10.1016/j.prosdent.2004.08.001)
- McGivney, G. P., & McCracken, W. L. (1995). *McCracken's removable partial prosthodontics* (Vol. 9): Mosby Elsevier Health Science.
- Medappa, P. (2018). *An in Vivo Study to Assess the Influence of Surface Roughness on Bacterial Adhesion in Polyether Ether Ketone (PEEK)* [Master Degree, Rajiv Gandhi University of Health Sciences, Bangalore, Karnataka]
- Messias, A., Neto, M. A., Amaro, A. M., Lopes, V. M., & Nicolau, P. (2021). Mechanical evaluation of implant-assisted removable partial dentures in Kennedy class I patients: finite element design considerations. *Applied Sciences*, 11(2), 659. <https://doi.org/10.3390/app11020659>
- Micovic, D., Mayinger, F., Bauer, S., Roos, M., Eichberger, M., & Stawarczyk, B. (2021). Is the high-performance thermoplastic polyetheretherketone indicated as a clasp material for removable dental prostheses? *Clinical Oral Investigations*, 25, 2859-2866. <https://doi.org/10.1007/s00784-020-03603-y>
- Mihalow, D. M., & Tinanoff, N. (1988). The influence of removable partial dentures on the level of *Streptococcus mutans* in saliva. *The Journal of Prosthetic Dentistry*, 59(1), 49-51. [https://doi.org/10.1016/0022-3913\(88\)90107-2](https://doi.org/10.1016/0022-3913(88)90107-2)
- Mine, K., Fueki, K., & Igarashi, Y. (2009). Microbiological risk for periodontitis of abutment teeth in patients with removable partial dentures. *Journal of Oral Rehabilitation*, 36(9), 696-702. <https://doi.org/10.1111/j.1365-2842.2009.01982.x>
- Mizuuchi, W., Yatabe, M., Sato, M., Nishiyama, A., & Ohyama, T. (2002). The effects of loading locations and direct retainers on the movements of the abutment tooth and denture base of removable partial dentures. *Journal of Medical And Dental Sciences*, 49(1), 11-18. <https://doi.org/10.11480/jmds.490102>
- Ministry of Health (2013). *National Oral Health Survey of Adults 2010 (NOHSA 2010)*. Malaysia

- Ministry of Health (2025). *National Oral Health Strategic Plan 2022-2030*. Malaysia: Oral Health Programme, Ministry of Health Malaysia
- Mohamed, S. E., & Rasha, H. G. (2019). Digital PEEK framework and patient satisfaction compared to conventional metal framework in removable partial dentures. A clinical trial. *Egyptian Dental Journal*, 65(4), 3787-3794. DOI: 10.21608/edj.2019.76027
- Mohammed, S., & Desai, H. (2014). Basic concepts of finite element analysis and its applications in dentistry: An overview. *Oral Hyg Health*, 2(156), 2332-0702.1000156. doi: 10.4172/2332-0702.1000156
- Mori, T., Togaya, T., Jean-Louis, M., & Yabugami, M. (1997). Titanium for removable dentures. I. Laboratory procedures. *Journal of Oral Rehabilitation*, 24(5), 338-341. <https://doi.org/10.1111/j.1365-2842.1997.tb00337.x>
- Mousa, M. A., Abdullah, J. Y., Jamayet, N. B., El-Anwar, M. I., Ganji, K. K., Alam, M. K., & Husein, A. (2021). Biomechanics in Removable Partial Dentures: A Literature Review of FEA-Based Studies. *BioMed Research International*, 2021, 699962. <https://doi.org/10.1155/2021/5699962>
- Muhsin, S. A., Hatton, P. V., Johnson, A., Sereno, N., & Wood, D. J. (2019). Determination of polyetheretherketone (PEEK) mechanical properties as a denture material. *The Saudi Dental Journal*, 31(3), 382-391. <https://doi.org/10.1016/j.sdentj.2019.03.005>
- Muhsin, S. A., Wood, D. J., & Johnson, A. (2018). Effects of novel polyetheretherketone (PEEK) clasp design on retentive force at different tooth undercuts. *Journal of Oral and Dental Research*, 5(2).
- Müller, S., Eickholz, P., Reitmeir, P., & Eger, T. (2013). Long-term tooth loss in periodontally compromised but treated patients according to the type of prosthodontic treatment. A retrospective study. *Journal of Oral Rehabilitation*, 40(5), 358-367. <https://doi.org/10.1111/joor.12035>
- Muraki, H., Wakabayashi, N., Park, I., & Ohyama, T. (2004). Finite element contact stress analysis of the RPD abutment tooth and periodontal ligament. *Journal of Dentistry*, 32(8), 659-665. <https://doi.org/10.1016/j.jdent.2004.07.003>
- Najeeb, S., Zafar, M. S., Khurshid, Z., & Siddiqui, F. (2016). Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. *Journal of Prosthodontic Research*, 60(1), 12-19. <https://doi.org/10.1016/j.jprior.2015.10.001>

- Nakamura, Y., Kanbara, R., Ochiai, K. T., & Tanaka, Y. (2014). A finite element evaluation of mechanical function for 3 distal extension partial dental prosthesis designs with a 3-dimensional nonlinear method for modeling soft tissue. *The Journal of Prosthetic Dentistry*, 112(4), 972-980. <https://doi.org/10.1016/j.prosdent.2014.03.011>
- Negm, E. E., Aboutaleb, F. A., & Alam-Eldein, A. M. (2019). Virtual evaluation of the accuracy of fit and trueness in maxillary poly (etheretherketone) removable partial denture frameworks fabricated by direct and indirect CAD/CAM techniques. *Journal of Prosthodontics*, 28(7), 804-810. <https://doi.org/10.1111/jopr.13075>
- Nevalainen, M., Närhi, T., & Ainamo, A. (2004). A 5-year follow-up study on the prosthetic rehabilitation of the elderly in Helsinki, Finland. *Journal of Oral Rehabilitation*, 31(7), 647-652. <https://doi.org/10.1111/j.1365-2842.2004.01280.x>
- Nishiyama, H., Taniguchi, A., Tanaka, S., & Baba, K. (2020). Novel fully digital workflow for removable partial denture fabrication. *Journal of Prosthodontic Research*, 64(1), 98-103. <https://doi.org/10.1016/j.jpor.2019.05.002>
- Oefner, C., Herrmann, S., Kebbach, M., Lange, H.-E., Klues, D., & Woiczinski, M. (2021). Reporting checklist for verification and validation of finite element analysis in orthopedic and trauma biomechanics. *Medical Engineering & Physics*, 92, 25-32. <https://doi.org/10.1016/j.medengphy.2021.03.011>
- Ogata, K., & Shimizu, K. (1991). Longitudinal study on forces transmitted from denture base to retainers of lower free-end saddle dentures with Aker's clasps. *Journal of Oral Rehabilitation*, 18(5), 471-480. <https://doi.org/10.1111/j.1365-2842.1991.tb01692.x>
- Ogimoto, T., Ogawa, T., Sumiyoshi, K., Matsuka, Y., & Koyano, K. (2002). Pressure–pain threshold determination in the oral mucosa: validity and reliability. *Journal of Oral Rehabilitation*, 29(7), 620-626. <https://doi.org/10.1046/j.1365-2842.2002.00874.x>
- Ohkubo, C., Hanatani, S., & Hosoi, T. (2008). Present status of titanium removable dentures—a review of the literature. *Journal of Oral Rehabilitation*, 35(9), 706-714. <https://doi.org/10.1111/j.1365-2842.2007.01821.x>

- Okabe, T., Ohkubo, C., Watanabe, I., Okuno, O., & Takada, Y. (1998). The present status of dental titanium casting. *JOM*, 50(9), 24-29. .
<https://doi.org/10.1007/s11837-998-0410-7>
- Oliveira, P. H. B. d., Ferreira, G. F., Gama, L. T., Carletti, T. M., & Rodrigues Garcia, R. C. M. (2025). Chewing with Co-Cr or PEEK denture frameworks: A randomized crossover clinical study. *Journal of Prosthodontics*.
<https://doi.org/10.1111/jopr.14039>Digital Object Identifier (DOI)
- Papathanasiou, I., Kamposiora, P., Papavasiliou, G., & Ferrari, M. (2020). The use of PEEK in digital prosthodontics: A narrative review. *BMC oral health*, 20(1), 1-11. <https://doi.org/10.1186/s12903-020-01202-7>
- Papathanasiou, I., Papavasiliou, G., Kamposiora, P., & Zoidis, P. (2022). Effect of staining solutions on color stability, gloss and surface roughness of removable partial dental prosthetic polymers. *Journal of Prosthodontics*, 31(1), 65-71. <https://doi.org/10.1111/jopr.13360>
- Peng, P. W., Chen, M.S., Peng, T.Y., Huang, P. C., Nikawa, H., & Lee, W. F. (2024). In vitro study of optimal removable partial denture clasp design made from novel high-performance polyetherketoneketone. *journal of prosthodontic research*, 68(3), 466-473.
- Peng, P.W., Hsu, C.Y., Huang, H.Y., Chao, J.C., & Lee, W.F. (2022). Trueness of removable partial denture frameworks additively manufactured with selective laser melting. *The Journal of Prosthetic Dentistry*, 127(1), 122-127. <https://doi.org/10.1016/j.prosdent.2020.06.035>
- Peng, T.Y., Ogawa, Y., Akebono, H., Iwaguro, S., Sugeta, A., & Shimoe, S. (2020). Finite-element analysis and optimization of the mechanical properties of polyetheretherketone (PEEK) clasps for removable partial dentures. *Journal of Prosthodontic Research*, 64(3), 250-256.DOI: 10.1016/j.jpor.2019.07.012
- Pereira, A. L. C., de Medeiros, A. K. B., de Sousa Santos, K., de Almeida, É. O., Barbosa, G. A. S., & Carreiro, A. d. F. P. (2021). Accuracy of CAD-CAM systems for removable partial denture framework fabrication: A systematic review. *The Journal of Prosthetic Dentistry*, 125(2), 241-248. <https://doi.org/10.1016/j.prosdent.2020.01.003>
- Phoenix, R. D., Cagna, D. R., & DeFreest, C. F. (2003). *Stewart's Clinical Removable Partial Prosthodontics*: Quintessence Chicago.

- Piwowarczyk, A., Köhler, K. C., Bender, R., Büchler, A., Lauer, H. C., & Ottl, P. (2007). Prognosis for abutment teeth of removable dentures: a retrospective study. *Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry*, 16(5), 377-382. <https://doi.org/10.1111/j.1532-849X.2007.00211.x>
- Polychronakis, N., Lagouvardos, P., Polyzois, G., Sykaras, N., & Zoidis, P. (2020). Color changes of polyetheretherketone (PEEK) and polyoxymethelene (POM) denture resins on single and combined staining/cleansing action by CIELab and CIEDE2000 formulas. *Journal of Prosthodontic Research*, 64(2), 159-166. <https://doi.org/10.1016/j.jpor.2019.06.005>
- Porojan, L., Toma, F. R., Vasiliu, R. D., Topală, F.I., Porojan, S. D., & Matichescu, A. (2021). Optical properties and color stability of dental PEEK related to artificial ageing and staining. *Polymers*, 13(23), 4102. <https://doi.org/10.3390/polym13234102>
- Qin, L., Yao, S., Zhao, J., Zhou, C., Oates, T. W., Weir, M. D., Xu, H. H. (2021). Review on development and dental applications of polyetheretherketone-based biomaterials and restorations. *Materials*, 14(2), 408. <https://doi.org/10.3390/ma14020408>
- Ramakrishnan, H., & Singh, R. G. (2010). Three-dimensional finite element analysis of the stress distribution pattern in the design modifications of U-shaped palatal major connector. *Indian Journal Of Dental Research*, 21(4), 506-511. DOI: 10.4103/0970-9290.74219
- Refai, O. M., Nawar, N. H., & Lebshtien, I. T. (2022). Assessment of retention of CAD-CAM Milled PEKK vs PEEK Double crown-retained removable partial dentures: A randomized clinical trial. *The Journal of Contemporary Dental Practice*, 22(11), 1250-1256.
- Reslan, M. R., Osman, E., Segaan, L., Rayyan, M., & Joukhadar, C. (2021). Comparison between integrated and parallel interlock designs of an extracoronal attachment-retained distal extension removable partial dentures: a clinical trial. *Journal of International Society of Preventive and Community Dentistry*, 11(1), 41-49. DOI: 10.4103/jispcd.JISPCD_337_20
- Rice, J., Lynch, C. D., McAndrew, R., & Milward, P. J. (2011). Tooth preparation for rest seats for cobalt–chromium removable partial dentures completed by general dental practitioners. *Journal of Oral Rehabilitation*, 38(1), 72-78. <https://doi.org/10.1111/j.1365-2842.2010.02130.x>

- Richert, R., Alsheghri, A. A., Alageel, O., Caron, E., Song, J., Ducret, M., & Tamimi, F. (2021). Analytical model of I-bar clasps for removable partial dentures. *Dental Materials*, 37(6), 1066-1072. DOI: 10.1016/j.dental.2021.03.018.
- Rocha, E. P., Francisco, S., Del Bel Cury, A., & Cury, J. (2003). Longitudinal study of the influence of removable partial denture and chemical control on the levels of *Streptococcus mutans* in saliva. *Journal of Oral Rehabilitation*, 30(2), 131-138. <https://doi.org/10.1046/j.1365-2842.2003.01015.x>
- Rodrigues, M. T., Gowda, B. H., & Alva, B. (2021). Stress distribution in tooth supported removable partial denture fabricated using two different materials: a 3-dimensional finite element analysis. *Materials Today: Proceedings*, 46, 7643-7650. <https://doi.org/10.1016/j.matpr.2021.01.943>
- Russo, L. L., Muzio, E. L., Troiano, G., & Guida, L. (2021). Cast-free fabrication of a digital removable partial denture with a polyetheretherketone framework. *The Journal of Prosthetic Dentistry*, 129 (2), 262-266 <https://doi.org/10.1016/j.prosdent.2021.06.008>
- Sabri, L. A., Abdulkareem, J. F., Salloomi, K. N., Faraj, S. A., Al-Zahawi, A. R., Abdullah, O. I., & Tulunoglu, I. (2022). Finite element analysis of class II mandibular unilateral distal extension partial dentures. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 236(17), 9407-9418. <https://doi.org/10.1177/095440622210966>
- Sandu, L., Topală, F., & Porojan, S. (2010). Stress distribution in retentive arms of combination clasps used on premolars. *Journal of Applied Biomaterials and Biomechanics*, 8(2), 76-81. <https://doi.org/10.1177/228080001000800>
- Sato, Y., Shindoi, N., Koretake, K., & Hosokawa, R. (2003). The effect of occlusal rest size and shape on yield strength. *The Journal of Prosthetic Dentistry*, 89(5), 503-507. [https://doi.org/10.1016/S0022-3913\(02\)52739-6](https://doi.org/10.1016/S0022-3913(02)52739-6)
- Sato, Y., Tsuga, K., Abe, Y., Asahara, S., & Akagawa, Y. (2001). Finite element analysis on preferable I-bar clasp shape. *Journal of Oral Rehabilitation*, 28(5), 413-417. <https://doi.org/10.1046/j.1365-2842.2001.00673.x>
- Saub, R., Locker, D., & Allison, P. (2005). Derivation and validation of the short version of the Malaysian Oral Health Impact Profile. *Community Dentistry and Oral Epidemiology*, 33(5), 378-383. <https://doi.org/10.1111/j.1600-0528.2005.00242>

- Schwitalla, A. D., Spintig, T., Kallage, I., & Müller, W.D. (2015). Flexural behavior of PEEK materials for dental application. *Dental Materials*, 31(11), 1377-1384. <https://doi.org/10.1016/j.dental.2015.08.151>
- Schwitalla, A. D., Zimmermann, T., Spintig, T., Kallage, I., & Müller, W.D. (2017). Fatigue limits of different PEEK materials for dental implants. *Journal of the Mechanical Behavior of Biomedical Materials*, 69, 163-168. <https://doi.org/10.1016/j.jmbbm.2016.12.019>
- Sepúlveda-Navarro, W. F., Arana-Correa, B. E., Ferreira Borges, C. P., Habib Jorge, J., Urban, V. M., & Campanha, N. H. (2011). Color stability of resins and nylon as denture base material in beverages. *Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry*, 20(8), 632-638. <https://doi.org/10.1111/j.1532-849X.2011.00791.x>
- Shahmiri, R., Aarts, J. M., Bennani, V., Atieh, M. A., & Swain, M. V. (2013). Finite element analysis of an implant-assisted removable partial denture. *Journal of Prosthodontics*, 22(7), 550-555. <https://doi.org/10.1111/jopr.12031>
- Shahmiri, R., & Das, R. (2017). Finite element analysis of implant-assisted removable partial dentures: Framework design considerations. *The Journal of Prosthetic Dentistry*, 118(2), 177-186. <https://doi.org/10.1016/j.prosdent.2016.10.032>
- Shahmiri, R., Das, R., Aarts, J. M., & Bennani, V. (2014). Finite element analysis of an implant-assisted removable partial denture during bilateral loading: occlusal rests position. *The Journal of Prosthetic Dentistry*, 112(5), 1126-1133. <https://doi.org/10.1016/j.prosdent.2014.04.023>
- Sharma, D., & Sharma, V. (2025). Biomechanical analysis of triply periodic minimal surfaces-based porous dental implants versus solid implants: impact of peri-implant bone density on micromotion. *Computer Methods in Biomechanics and Biomedical Engineering*, 1-21. <https://doi.org/10.1080/10255842.2025.2472018>
- Shimura, Y., Wadachi, J., Nakamura, T., Mizutani, H., & Igarashi, Y. (2010). Influence of removable partial dentures on the formation of dental plaque on abutment teeth. *Journal of Prosthodontic Research*, 54(1), 29-35. <https://doi.org/10.1016/j.jpor.2009.08.003>
- Shivakumar, S., Kudagi, V. S., & Talwade, P. (2021). Applications of finite element analysis in dentistry: A review. *Journal of International Oral Health*, 13(5), 415-422. DOI: 10.4103/JIOH.JIOH_11_21

- Sinha, N., Gupta, N., Reddy, K. M., & Shastry, Y. (2017). Versatility of PEEK as a fixed partial denture framework. *The Journal of the Indian Prosthodontic Society*, 17(1), 80. DOI: 10.4103/0972-4052.197941
- Soares, L. F., Costa, M. S., Junior, J. F., de Almeida, A. L. P., & Porto, V. C. (2025). Do clasps made of thermoplastic polymers ensure adequate retention for removable partial dentures? A systematic review and meta-analysis. *The Journal of Prosthetic Dentistry*. <https://doi.org/10.1016/j.prosdent.2025.06.021>
- Soltanzadeh, P., Suprono, M. S., Kattadiyil, M. T., Goodacre, C., & Gregorius, W. (2019). An in vitro investigation of accuracy and fit of conventional and CAD/CAM removable partial denture frameworks. *Journal of Prosthodontics*, 28(5), 547-555. <https://doi.org/10.1111/jopr.12997>
- Su, M. Z., Chang, H. H., Chiang, Y. C., Cheng, J. H., Fuh, L. J., Wang, C. Y., & Lin, C. P. (2013). Modeling viscoelastic behavior of periodontal ligament with nonlinear finite element analysis. *Journal of Dental Sciences*, 8(2), 121-128. <https://doi.org/10.1016/j.jds.2013.01.001>
- Tada, S., Allen, P. F., Ikebe, K., Matsuda, K.I., & Maeda, Y. (2015). Impact of periodontal maintenance on tooth survival in patients with removable partial dentures. *Journal of Clinical Periodontology*, 42(1), 46-53. <https://doi.org/10.1111/jcpe.12320>
- Tada, S., Ikebe, K., Matsuda, K.-i., & Maeda, Y. (2013). Multifactorial risk assessment for survival of abutments of removable partial dentures based on practice-based longitudinal study. *Journal of Dentistry*, 41(12), 1175-1180.
- Tamimi, F., Almufleh, B., Caron, E., & Alageel, O. (2020). Digital removable partial dentures. *Clinical Dentistry Reviewed*, 4(1), 1-12. <https://doi.org/10.1007/s41894-020-00074-y>
- Tannous, F., Steiner, M., Shahin, R., & Kern, M. (2012). Retentive forces and fatigue resistance of thermoplastic resin clasps. *Dental Materials*, 28(3), 273-278. <https://doi.org/10.1016/j.dental.2011.10.016>
- Tasaka, A., Uekubo, Y., Mitsui, T., Kasahara, T., Takanashi, T., Homma, S., Yajima, Y. (2019). Applying intraoral scanner to residual ridge in edentulous regions: in vitro evaluation of inter-operator validity to confirm trueness. *BMC Oral Health*, 19(1), 264. <https://doi.org/10.1186/s12903-019-0918-y>
- Tribst, J. P. M., Dal Piva, A. M. d. O., Borges, A. L. S., Araújo, R. M., da Silva, J. M. F., Bottino, M. A., de Jager, N. (2020). Effect of different materials and undercut

- on the removal force and stress distribution in circumferential clasps during direct retainer action in removable partial dentures. *Dental Materials*, 36(2), 179-186. <https://doi.org/10.1016/j.dental.2019.11.022>
- Trivedi, S. (2014). Finite element analysis: A boon to dentistry. *Journal of Oral Biology and Craniofacial Research*, 4(3), 200-203. <https://doi.org/10.1016/j.jobcr.2014.11.008>
- van Eck, N. J., & Waltman, L. (2011). VOSviewer manual. *Manual for VOSviewer version*, 1(0).
- Vanzeveren, C., D'hoore, W., & Bercy, P. (2002). Influence of removable partial denture on periodontal indices and microbiological status. *Journal of Oral Rehabilitation*, 29(3), 232-239. <https://doi.org/10.1046/j.1365-2842.2002.00854.x>
- Wakabayashi, N., Ona, M., Suzuki, T., & Igarashi, Y. (2008). Nonlinear finite element analyses: advances and challenges in dental applications. *Journal of Dentistry*, 36(7), 463-471. <https://doi.org/10.1016/j.jdent.2008.03.010>
- Walter, R. D., Brudvik, J. S., Raigrodski, A. J., Mancl, L. A., & Chung, K.H. (2010). A comparison of the rigidity of five mandibular major connectors for partial removable dental prostheses via load deflection. *The Journal of Prosthetic Dentistry*, 104(3), 182-190. [https://doi.org/10.1016/S0022-3913\(10\)60118-7](https://doi.org/10.1016/S0022-3913(10)60118-7)
- Wataha, J. C. (2002). Alloys for prosthodontic restorations. *The Journal of Prosthetic Dentistry*, 87(4), 351-363.
- Williams, R., Bibb, R., Eggbeer, D., & Collis, J. (2006). Use of CAD/CAM technology to fabricate a removable partial denture framework. *The Journal of Prosthetic Dentistry*, 96(2), 96-99. <https://doi.org/10.1016/j.prosdent.2006.05.029>
- Wu, Q., Zhang, N., Dong, B., Sun, M., Yang, X., & Yu, H. (2022). Esthetic rehabilitation for a Kennedy Class IV patient using detachable 3D printing diagnostic denture and removable partial denture with polyetheretherketone framework. *Heliyon*, 8(10), e10834. DOI: 10.1016/j.heliyon.2022.e10834
- Yang, C., Tian, X., Li, D., Cao, Y., Zhao, F., & Shi, C. (2017). Influence of thermal processing conditions in 3D printing on the crystallinity and mechanical properties of PEEK material. *Journal of Materials Processing Technology*, 248, 1-7. <https://doi.org/10.1016/j.jmatprotec.2017.04.027>
- Ye, H., Li, X., Wang, G., Kang, J., Liu, Y., Sun, Y., Kang, J. (2018). A Novel Computer-Aided Design/Computer-Assisted Manufacture Method for One-Piece

- Removable Partial Denture and Evaluation of Fit. *International Journal of Prosthodontics*, 31(2). DOI: 10.11607/ijp.5508
- Yeung, A., Lo, E., Chow, T., & Clark, R. (2000). Oral health status of patients 5–6 years after placement of cobalt–chromium removable partial dentures. *Journal of Oral Rehabilitation*, 27(3), 183-189. <https://doi.org/10.1046/j.1365-2842.2000.00512.x>
- Yoon, J. m., Liu, Y., Sun, Y., Ye, H., & Zhou, Y. (2024). Clinical evaluation of a one-piece polyetheretherketone removable partial denture fabricated using a novel digital workflow: A self-controlled clinical trial. *Journal of Prosthodontics*, 33(8), 757-763. <https://doi.org/10.1111/jopr.13907>
- Yusof, Z., & Isa, Z. (1994). Periodontal status of teeth in contact with denture in removable partial denture wearers. *Journal of Oral Rehabilitation*, 21(1), 77-86. <https://doi.org/10.1111/j.1365-2842.1994.tb01126.x>
- Zhai, T., Li, M., Zheng, Y., & Wang, Z. (2025). Evaluate the clinical performance of Bio-HPP and Vitallium frameworks in free-end removable partial dentures. *Scientific reports*, 15(1), 28777. <https://doi.org/10.1038/s41598-025-11370-7>
- Zheng, J., Aarts, J. M., Ma, S., Waddell, J. N., & Choi, J. J. E. (2023). Different Undercut Depths Influence on Fatigue Behavior and Retentive Force of Removable Partial Denture Clasp Materials: A Systematic Review. *J Prosthodont*, 32(2), 108-115. doi:10.1111/jopr.13519
- Zoidis, P., Papathanasiou, I., & Polyzois, G. (2016). The use of a modified poly-ether-ether-ketone (PEEK) as an alternative framework material for removable dental prostheses. A clinical report. *Journal of Prosthodontics*, 25(7), 580-584. <https://doi.org/10.1111/jopr.12325>
- Zol, S. M., Alauddin, M. S., Said, Z., Mohd Ghazali, M. I., Hao-Ern, L., Mohd Farid, D. A., Abdul Aziz, A. H. (2023). Description of poly (aryl-ether-ketone) materials (PAEKs), polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) for application as a dental material: A materials science review. *Polymers*, 15(9), 2170. <https://doi.org/10.3390/polym15092170>

APPENDICES

APPENDIX 1

Ethical approval letter

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Pejabat
Timbalan Naib Canselor
(Penyelidikan dan Inovasi)

Reference : 600-TNCPI (5/1/6)
Our reference : REC/08/2023 (PG/FB/14)
Date : 16 August 2023

Profesor Dr Rohana binti Ahmad
(Nor Faharina Abdul Hamid – 2022494548)
Centre of Restorative Dentistry
Faculty of Dentistry
UiTM Sungai Buloh Campus
Jalan Hospital
47000 Sungai Buloh
SELANGOR

Dear Profesor Dr Rohana,

APPROVAL LETTER - UiTM RESEARCH ETHICS COMMITTEE

Thank you for submitting your research proposal to the Research Ethics Committee (REC). After reviewing the list of documents as attached the Committee approved your proposal titled "The Effect of Metal- and Polymer-Based Removable Partial Denture Framework on the Prognosis of Terminal Abutment Tooth" at the Faculty of Dentistry, Universiti Teknologi MARA.

Details of the approval are as follows:

Approval number:	REC/08/2023 (PG/FB/14)
Approval Period:	16 August 2023 until 2 October 2025
Authorised personnel:	1. Profesor Dr Rohana binti Ahmad 2. Nor Faharina Abdul Hamid 3. Prof. Ir Ts Dr Solehuddin bin Shuib 4. Dr Farha binti Ariffin

The UiTM Research Ethics Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The approval of this project is conditional upon your continuing compliance with these guidelines and declaration.

Failure to submit reports will result in withdrawal of consent for the project to proceed. Amendments, if any, to the study documents are to be submitted to the REC for approval.

If you require further information, please contact the REC Secretariat at 03-55448069/03-55442794 or email at recsecretariat@uitm.edu.my.

Yours sincerely,

EMERITUS PROFESSOR DATO' DR RAYMOND AZMAN ALI
Chairman
UiTM Research Ethics Committee

c.c.: Dean, Faculty of Dentistry, UiTM

Universiti Teknologi MARA
Aras 3, Bangunan Wawasan
40450 Shah Alam, Selangor, MALAYSIA
Tel: (+603) 5544 2004/2255
Faks: (+603) 5544 2070



APPENDIX 2

Consent Form

Consent form in Malay

REC 4 I 2020/BM Pind. 2(2020)

Jawatankuasa Etika Penyelidikan

Pusat Pengurusan Penyelidikan

Universiti Teknologi MARA

40450 SHAH ALAM

Tel: 03-5544-8069, Faks: 03-5544-2096/2767

Borang Maklumat Subjek



Tajuk Penyelidikan

Kesan Pemakaian Kerangka Gigi Palsu Sebahagian Berasaskan Logam- dan Polimer- terhadap Prognosis Gigi Terminal Abutmen

Pengenalan penyelidikan

Anda dijemput untuk mengambil bahagian secara sukarela dalam penyelidikan ini. Penyelidikan ini adalah berkaitan kesan pemakaian kerangka gigi palsu sebahagian berasaskan logam- dan polimer- terhadap prognosis gigi terminal abutment. Adalah penting anda membaca dan memahami maklumat penyelidikan ini sebelum bersetuju untuk menyertai kajian ini. Anda akan menerima salinan borang ini untuk disimpan sebagai rekod anda jika anda bersetuju untuk mengambil bahagian.

Tujuan penyelidikan

Tujuan kajian ini adalah untuk menentukan kesan pemakaian kerangka gigi palsu sebahagian berasaskan logam- dan polimer- terhadap prognosis gigi terminal abutmen.

Prosedur penyelidikan

Sekiranya anda bersetuju untuk mengambil bahagian dalam kajian ini, anda akan menerima sama ada kerangka gigi palsu sebahagian berasaskan logam- dan polimer. Anda akan diminta untuk menghadiri sesi klinikal sekurang-kurangnya sebanyak sembilan (9) sesi untuk pembuatan gigi palsu sebahagian. Ini merangkumi sesi konsultasi dan impresi pertama, impresi kedua, percubaan kerangka, percubaan gigi, pemberian gigi palsu, semakan selepas satu minggu, satu bulan, enam bulan dan satu tahun. Pemeriksaan akan dijalankan untuk menentukan tahap kesihatan gigi terminal abutmen sepanjang pemakaian gigi palsu sebahagian berasaskan logam- atau polimer di mana pesakit akan di pantau selama satu tahun.

Penyertaan dalam penyelidikan

Penyertaan anda di dalam penyelidikan ini adalah secara sukarela. Anda berhak menolak tawaran penyertaan ini atau menarik diri daripada penyelidikan ini pada bila-bila masa tanpa sebarang penalti.

Manfaat penyelidikan

Maklumat yang didapati dari penyelidikan ini akan memanfaatkan individu, penyelidik, institusi dan komuniti dalam kemajuan pengetahuan dan amalan pergigian.

Risiko penyelidikan

Kami tidak menjangkakan sebarang risiko kepada anda atau keluarga terdekat anda, sekiranya

anda mengambil bahagian dalam kajian ini. Waiau bagaimanapun, jika responden mengalami sebarang masalah pergigian atau periodontal, termasuk iritasi tisu disebabkan prostesis mereka, mereka akan dinasihatkan untuk mendapatkan temujanji, dan rawatan yang bersesuaian akan dilakukan. Prostesis akan ditanggalkan jika terdapat sebarang mobiliti gigi tan pa kehadiran plak, di mana penyiasatan serta rawatan yang sesuai akan diberikan kepada pesakit.

Kerahsiaaan

Maklumat anda akan dirahsiakan oleh penyelidik dan tidak akan didedahkan melainkan jika ia dikehendaki oleh undang-undang. Dengan menandatangani borang persetujuan ini, anda membenarkan penelitian rekod, penganalisan dan penggunaan data hasil daripada penyelidikan ini. Sekiranya anda mempunyai sebarang pertanyaan mengenai penyelidikan ini atau hak-hak anda, sila hubungi: Dr Nor Faharina Abdul Hamid (MDC No: 4107) Fakulti Pergigian, Universiti Teknologi MARA, Kampus Sungai Buloh, Sungai Buloh Selangor No Tel: 03-61266593 Email: faharina@ uitm.edu.my

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Borang Izin¹

Untuk menyertai penyelidikan ini, anda atau penjaga sah perlu menandatangani Borang Izin ini. Saya dengan ini mengesahkan bahawa saya telah memenuhi syarat umur dan berupaya bertindak bagi pihak saya sendiri/ sebagai² penjaga yang sah dalam perkara-perkara berikut:

1. Saya memahami ciri-ciri dan skop penyelidikan ini.
2. Saya telah membaca dan memahami semua syarat penyertaan penyelidikan ini.
3. Saya berpuas hati dengan jawapan pada kemusykilan saya tentang penyelidikan ini.
4. Saya secara sukarela bersetuju menyertai penyelidikan ini dan mengikuti segala aturan cara dan memberi maklumat yang diperlukan kepada penyelidik seperti yang dikehendaki.
5. Saya boleh menarik diri daripada penyelidikan ini pada bila-bila masa tanpa memberi sebab.
6. Saya telah pun menerima satu salinan Borang Maklumat Subjek dan Borang Izin.
7. Selain daripada kecederaan yang disebabkan oleh kelalaian dan kecuaiannya penyelidik, saya dengan ini melepaskan dan menggugurkan UiTM dan semua penyelidik dari semua liabiliti berhubung dengan, wujud dari atau berkaitan dengan penyertaan saya. Saya bersetuju untuk menjadikan mereka tidak bertanggungjawab terhadap apa-apa kemudaratan atau kerugian yang mungkin akan saya tanggung disebabkan oleh penyertaan saya.

Nama Subjek/ Wakil Sah yang berkuatkuasa

Tandatangan

No kad pengenalan

Tarikh

Nama Saksi³

Tandatangan

No. Kad Pengenalan

Tarikh

Nama Penyelidik/Pengambil Izin

Tandatangan

No. Kad Pengenalan

Tarikh

¹ Salinan asal disimpan oleh Penyelidik Utama dan satu salinan diserahkan kepada subjek.

² Potong mana yang tidak berkenaan.

³ Saksi dimestikan bagi izin secara lisa

Consent form in English

REC 4 I 2020/BM Pind. 2(2020)

Jawatankuasa Etika Penyelidikan

Pusat Pengurusan Penyelidikan

Universiti Teknologi MARA

40450 SHAH ALAM

Tel: 03-5544-8069, Faks: 03-5544-2096/2767

Subject Information Sheet



Research Title

The Effect of Metal- And Polymer-Based Removable Partial Denture Framework on The Prognosis of Terminal Abutment Tooth

Introduction of Research

You are invited to take part voluntarily in research. This research is about the effect of metal- and polymer- based removable partial denture framework on the prognosis of terminal abutment tooth. It is important that you read and understand this research information before agreeing to participate in this study. You will receive a copy of this form to keep for your records if you agree to participate.

Purpose of Research

The purpose of this study is determining the effect of metal- and polymer-based removable partial denture framework on the prognosis of terminal abutment tooth.

Research Procedure

If you agree to participate in this study, you will receive either a metal- and polymer-based partial denture framework. You will be required to attend a minimum of nine clinical sessions for the fabrication of partial dentures. This includes a consultation session and first impression, second impression, framework try-in, try-in denture, denture delivery, review after one week, one month, six months and one year. An examination will be conducted to determine the condition of terminal abutment terminal teeth throughout the use of metal- or polymer-based partial dentures where the patient will be monitored for one year.

Participation in Research

Your participation in this research is entirely voluntary. You may refuse to take part in the study or you may withdraw yourself from participation in the research at any time without penalty.

Benefit of Research

Information obtained from this research will benefit the individuals, researchers, institution and community for the advancement of knowledge and future dental practice.

Research Risk

We do not anticipate any risks to you or your immediate family, by participating in this study. However, if the respondent experiences any dental or periodontal problems, including tissue irritation from their prostheses, they will be advised to schedule an appointment, and necessary treatment will be provided. The prosthesis will be removed if any excessive mobility of an abutment tooth without the presence of plaque is found, and appropriate investigation and treatment will be provided.

Confidentiality

Your information will be kept confidential by the investigators and will not be made public

unless disclosure is required by law. By signing this consent form, you will authorize the review of records, analysis and use of the data arising from this research. If you have any question about this research or your rights, please contact: Dr Nor Faharina Abdul Hamid (MDC No: 4107) Fakulti Pergigian, Universiti Teknologi MARA, Kampus Sungai Buloh, Sungai Buloh Selangor No Tel: 03-61266593 Email: faharina@uitm.edu.my

Consent Form¹

To become a subject in the research, you or your legal guardian are required to sign this Consent Form

I herewith confirm that I have met the requirement of age and am capable of acting on behalf of myself *I* as ² a legal guardian as follow:

1. I understand the nature and scope of the research being undertaken.
2. I have read and understood all the terms and conditions of my participation in the research.
3. All my questions relating to this research and my participation therein have been answered to my satisfaction.
4. I voluntarily agree to take part in this research, to follow the study procedures and to provide all necessary information to the investigators as requested.
5. I may at any time choose to withdraw from this research without giving any reason.
6. I have received a copy of the Subjects Information Sheet and Consent Form.
7. Except for damages resulting from negligent or malicious conduct of the researcher(s), I hereby release and discharge UiTM and all participating researchers from all liability associated with, arising out of, or related to my participation. I agree to hold them harmless from any harm or loss that may be incurred by me due to my participation in the research.

Name of Subject/Legally authorized representative (LAR)	Signature
---	-----------

I.C No	Date
--------	------

Name of witness ³	Signature
------------------------------	-----------

I.C No	Date
--------	------

Name of Consent Taker	Signature
-----------------------	-----------

I.C No	Date
--------	------

¹Original signed copy is to be retained by the Principal Investigator.

²Delete whichever is not applicable.

³A witness is only required for oral consent

APPENDIX 3

Data collection form

Date	
Session	Baseline/ 1 month/ 6 month
Patient Code	
Case*	Cobalt-Chromium/ PEEK

Clinical examination *(following Black Classification)*

Abutment tooth:	Abutment tooth:
Sound/ Restoration/ Caries	Sound/Restoration Caries
Location/extension:	Location/extension:

Periodontal examination

Plaque index (Silness and Loe, 1964)					
Score	Description				
0	No plaque				
1	Thin plaque layer at the gingival margin, only detectable by scraping with a probe				
2	Moderate layer of plaque along with the gingival margin but plaque visible to the naked eyes				
3	Abundant plaque along the gingival margin, interdental spaces filled with plaque				
X	Excluded				

$$PI = \frac{\text{Sum of plaque}}{4 \text{ surface} \times \text{Number of teeth}}$$

16	12	24	36	32	44

Plaque index: _____

Plaque score/ Bleeding score (Ainamo & Bay 1975)

Plaque score %																			
Date _____	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8			

Bleeding score %																			
Date _____	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8			

Plaque score (%) = Bleeding score (%) =

Gingival index (GI) (Silness and Loe, 1963)

Score	Description
0	Normal gingiva; no inflammation; no discoloration (erythema); no bleeding
1	Mild inflammation; slight erythema; no bleeding
2	Moderate inflammation; erythema; bleeding on probing
3	Severe inflammation; severe erythema and swelling; tendency to spontaneous bleeding; possible ulceration
X	Excluded

GI= $\frac{\text{Sum of GI}}{4 \text{ surface} \times \text{Number of teeth}}$

16	12	24	36	32	44

Gingival index: _____

Probing pocket depth

Abutment tooth:

D-B	Mid-B	M-B
D-L	Mid-L	M-L

Abutment tooth:

M-B	Mid-B	D-B
M-L	Mid-L	D-L

Mobility (Miller, 1985)

Abutment	Grade
Abutment	Grade

Recession

Abutment	Yes/ No
Abutment	Yes/No

M-B	Mid-B	D-B
M-L	Mid-L	D-L

M-B	Mid-B	D-B
M-L	Mid-L	D-L

Data collection form



Short version of the Malaysian Oral Health Impact Profile

Introduction

The Malaysian Oral Health Impact Profile (OHIP-M) is a shortened version of the Oral Health Impact Profile (OHIP), a widely used tool for assessing the social impact of oral health conditions on an individual's quality of life. The OHIP-M is designed to be culturally relevant and applicable to the Malaysian population. It evaluates various dimensions of oral health-related quality of life, including functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap.

Pengenalan

Profil Kesan Kesihatan Mulut Malaysia (OHIP-M) adalah versi pendek dari Profil Kesan Kesihatan Mulut (OHIP), alat yang digunakan secara meluas untuk menilai kesan sosial keadaan kesihatan mulut terhadap kualiti hidup seseorang individu. OHIP-M direka untuk relevan kepada budaya dan sesuai untuk populasi Malaysia. Ia menilai pelbagai dimensi kualiti hidup berkaitan kesihatan mulut, termasuk had fungsi, kesakitan fizikal, ketidakselesaan psikologi, kecacatan fizikal, kecacatan psikologi, kecacatan sosial, dan kekurangan.

Sociodemographic characteristic

Age/ Umur : _____ years/tahun

Gender/ Jantina:

☐	Male/ Lelaki
☐	Female/ Perempuan

Ethnicity/ Bangsa:

☐	Malay/ Melayu
☐	Chinese/ Cina
☐	Indian/ Indian
☐	Others/ Lain-lain

Education level/ Taraf Pendidikan:

☐	No formal education/ Tiada Pendidikan formal
☐	Primary education/ Pendidikan Rendah
☐	Secondary education/ Pendidikan Menengah
☐	University/ Universiti

Treatment stage/ Peringkat rawatan

☐	Pre
☐	Post

Denture/ Gigi palsu

☐	Metal/ Besi
☐	Polymer/ Polimer

Oral Health Impact Profile Questionnaire

1. Pernahkah anda mengalami kesukaran mengunyah sebarang makanan disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Have you experienced difficulty chewing any food because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

2. Pernahkah anda merasakan yang masalah gigi, gusi, mulut atau gigi palsu anda menyebabkan nafas anda berbau?
(Have you felt problems related to your teeth, gum, mouth or dentures cause bad breath?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

3. Pernahkah anda mengalami rasa tidak selesa untuk makan sebarang makanan disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Have you experienced discomfort eating any food because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

4. Pernahkah anda mengalami tompok-tompok putih yang pedih (ulser) di dalam mulut?
(Have you experienced ulcers in your mouth?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

5. Pernahkah anda merasa tidak selesa disebabkan makanan terlekat di celah gigi atau gigi palsu anda?
(Have you felt discomfort due to food getting stuck in between your teeth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

6. Pernahkah anda merasa malu disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Have you felt shy because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Sese kali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

7. Pernahkah anda mengelak daripada memakan makanan tertentu disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Have you avoided eating certain foods because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Sese kali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

8. Pernahkah anda mengelak daripada senyum disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Have you avoided smiling because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Sese kali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

9. Pernahkah tidur anda terganggu disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Has your sleep been disturbed because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Sese kali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

10. Pernahkah tumpuan anda terganggu disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?
(Has your concentration been disturbed by problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Sese kali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

11. Pernahkah anda mengelak daripada keluar berjalan-jalan disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?

(Have you avoided going out because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

12. Pernahkah anda mengalami masalah untuk menjalankan kerja-kerja harian anda disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?

(Have you experienced problems in carrying out your daily activities because of problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

13. Pernahkah anda terpaksa mengeluarkan perbelanjaan yang tinggi disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?

(Have you had to spend a lot of money due to problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

14. Pernahkah anda merasa kurang yakin dengan diri anda disebabkan masalah gigi, gusi, mulut atau gigi palsu anda?

(Have you felt less confident of yourself due to problems with your teeth, gum, mouth or dentures?)

☐	Never/ Tidak pernah
☐	Hardly ever/ Jarang
☐	Occasionally/ Seseekali
☐	Fairly often/ Agak kerap
☐	Often/ Kerap

Thank you for your co-operation/ Terima kasih atas kerjasama anda.

APPENDIX 4

Poster presentation in conference



IADR
International Association
for Dental Research

Science Mapping of Research Clusters and Core Research Areas in Removable Partial Dentures

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Background

Science mapping is a visual representation of bibliometric data that allows researchers to explore the structure and dynamics of scientific knowledge (1,2). It is used by researchers to gain a comprehensive understanding of the emerging research patterns in a specific field, thereby aiding them in directing their research endeavors. Using co-occurrence analysis, researchers are able to identify and illustrate major research themes, knowledge groups, and future research opportunities in the field (2,3).

Objectives

- To describe the characteristics of RPDs-related research between year 2012-2022.
- To identify the research clusters and research cores in RPDs-related research based on co-occurrence analysis of the keywords.
- To identify high impact terms in RPDs-related research for the past ten years.

Methods

Data extraction and screening

Date: July 7, 2023
Search string: ("removable partial denture*" OR "removable prosth*")
Year : 2012-2022 (n= 1670)

Filter:

Subject area: Dentistry; Document type: Article, Review; Publication stage: Final, Article in press; Language: English (n= 1043)

Data cleaning

Remove duplications and irrelevant articles (n=888)

Data analysis

Descriptive analysis
Bibliometric analysis : Science mapping of co-occurrence keywords







Key findings

Timespan	Sources	Documents	Annual Growth Rate
2012:2022	114	888	-1.34 %
Authors	Authors of single-authored docs	International Co-Authorship	Co-Authors per Doc
2773	40	18.92 %	4.56
Author's keywords (n)	References	Document Average Age	Average citations per doc
1597	21249	6.05	9.934

Figure 1. Main information of RPDs- related research for the past ten years (2012-2022)

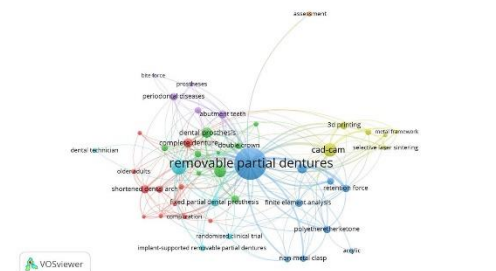


Figure 2. Co-occurrence of keywords in RPDs research from 679 keywords; with a minimum number of five, 46 keywords meet the threshold. The size of the label and the circle of the item is determined by its weight; the higher the weight of the keyword, the larger the label and the circle. The distance between two keywords indicates the relatedness of the keywords in terms of co-citation links. The closer two keywords are to each other, the stronger their relatedness.

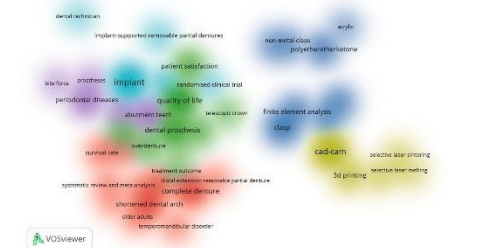


Figure 3. Cluster density visualisation reveals six major research clusters in the RPDs

Table 1. Average citation (AC)* and average normalised citation (ANC)* scores of high-impact keywords from 2012 to 2022

Keywords	Average citations	Average normalised citations	Average Publication Year
polyetheretherketone (PEEK)	34.7	3.0708	2020
3D printing	26.4	2.3515	2019
systematic review	20.5	1.7695	2016
implant-supported FPDs	19.6	1.4788	2017
clinical trial	19.6	1.6477	2016
implant	19.0	1.6342	2016
selective laser sintering	18.8	2.3461	2019
non-metal clasp	17.5	1.7409	2017
cad-cam	16.6	1.8467	2019
thermoplastic resin	15.9	1.5433	2017

*AC : the average number of citations received by the documents published by an author, a source, an organization, or a country (4)
*ANC : The average normalized number of citations received by the documents in which a keyword or a term occurs or the average normalized number of citations received by the documents published by a source, an author, an organization, or a country (4)

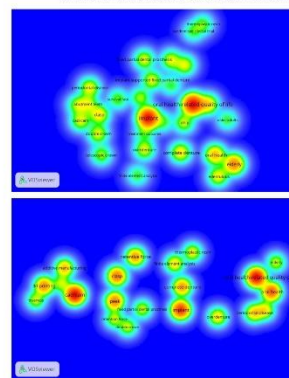


Figure 5. The co-occurrence network distribution density reflects how "hot" or "cold" a research topic was in a 5-year interval.

- For years 2012–2017: The primary research core areas (marked in red) are "Implant" and "oral-health-quality of life".
- For years 2018–2022: Emerging research includes digital technologies in RPDs fabrication, research on clasps and PEEK.

Conclusions

- Mapping and identifying emergent themes provide directions for future research, which can be regarded as a beneficial contribution to the research's progress.
- PEEK has been identified as the highest impact terms for the past ten years, highlighting the possible future research interest in RPDs-related research.
- Incorporating digital technologies in RPDs fabrication, either additive manufacturing (3D printing/laser sintering) or subtractive manufacturing (CAD/CAM) using new polymers as materials, are expected to increase in the future.

References

1. Joshi MA (2015). Bibliometric indicators for evaluating the quality of scientific publications. 1. Contemporary. Dent. Pract.
2. Dineen N, Kumar S, Mullerjens G, Hendry N, Lin WM (2017). How to conduct a bibliometric analysis: An overview and guidelines. J. Bus. Res. 158:285–296.
3. Alkhatib MN, Al-Sunabati FA, Alkhatib AA, Smeiri A, Alenbani A, Samran A (2022). Bibliometric analysis and evaluation of the Journal of Prosthetic Dentistry from 1990 to 2020. J. Prosthet. Dent.
4. von Glöck, Waltham L (2008). VOSviewer manual. Manual for VOSviewer version 1.6.8.

APPENDIX 5

Certificate of Achievement



Certificate of achievement



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OF ACHIEVEMENT

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DR NOR FAHARINA ABDUL HAMID

for being **1st** place 3MT (PHD) in the

1st UiTM DENTAL POSTGRADUATE
SCIENTIFIC SYMPOSIUM (DPgSS)

16-17 JULY 2024

Prof Dr Nur Aida Asyikin
Abd Rahman
Dean
Faculty of Dentistry
Universiti Teknologi Mara

Dr Marlena Kamaruzaman
Program Director
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Scientific Symposium (DPgSS)

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UK
group.cochrane.org

This certificate is awarded to

Dr Nor Faharina Abdul Hamid
Universiti Teknologi MARA

For their attendance at the
Introduction to
Cochrane Systematic Reviews:
Protocol Development Workshop
29 November – 1 December 2022

Certificate of participation



Certificate of Achievement

This is to certify that

Nor Faharina Binti Abdul Hamid

NRIC No.: 830721-01-5644

Had successfully participated in a Good Clinical Practice course on

4 - 6 October 2022

Selangor

And has fulfilled the condition to be GCP certified on

06 October 2022

Selangor

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Tan Sri Dato' Seri Dr. Noor Hisham bin Abdullah

Director General of Health &
Chairman of National Committee for Clinical Research

NCCR2022-1842



Certificate of participation



Institut
Pengajian Siswazah



CERTIFICATE OF PARTICIPATION

Presented to
NOR FAHARINA ABDUL HAMID

from
FACULTY OF DENTISTRY

has participated in the
**2024 UiTM THREE MINUTE THESIS (3MT)
COMPETITION**

on
21st MAY 2024

Prof. Ir. Dr. Zuhaina Hj. Zakaria

Dean

Institute of Postgraduate Studies (IPSiS)



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No. A01196

Nor Faharina Abdul Hamid 様

公益社団法人日本補綴歯科学会第133回学術大会
(the 14th Biennial Congress of the Asian Academy
of Prosthodontics (AAP) 共催)に参加されたことを証明
いたします。

This is to certify that your have participated in
the 133rd Annual Meeting of the Japan Prosthodontic
Society and the 14th Biennial Congress of
the Asian Academy of Prosthodontics (AAP).

2024年7月5日(金)～7日(日)

July 5th - 7th, 2024

公益社団法人日本補綴歯科学会第133回学術大会

The 14th Biennial Congress of the Asian Academy of Prosthodontics (AAP)

公益社団法人日本補綴歯科学会第133回学術大会

大会長 河相 安彦 (Yasuhiko Kawai)

The 14th Biennial Congress of the Asian Academy of Prosthodontics

Congress Chair Takuo Kuboki



Certificate of participation



APPENDIX 6

Publications



A Bibliometric Analysis of Removable Partial Denture-related Research in Dentistry

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To link to this article: <https://doi.org/10.21315/aos2023.1802.RV03>

(Note: Journal Admin will provide the final DOI)

ABSTRACT

The objective of this study was to characterize articles published in removable partial denture (RPD) research from 1948–2022 in order to identify the most influential journals, publications, authors, and core research areas using bibliometric analysis. The Scopus database was used to retrieve publications with titles containing the truncated search term ("removable partial denture*" OR "removable prosthodontics*"). Data analysis and visualization were done using Microsoft Excel, Biblioshiny software and VOSviewer. 2,484 articles were analysed from 1948 till 2022, representing an annual growth rate of 4.9%. The Journal of Prosthodontic Research demonstrated the highest average normal citation rate, with productive authors with highest citations being from Japan. From 1948–1999, most in-vitro and clinical research focused on the basic concept of RPD using cobalt-chromium as a framework before shifting to titanium in 2000. RPD research after 2012 focuses on new technology and non-metal-based frameworks as an alternative to metal-based frameworks. Wakabayashi, N. and Fueki, K. were the most prominent researchers, according to a three-field plot analysis, with the Journal of Prosthetic Dentistry, Journal of Oral Rehabilitation, and Journal of Prosthodontic Research among the authors' preferred journals. "CAD/CAM" and "3D printing" were identified as emerging themes in year 2020–2022, while "selective laser melting" was the trending keyword in 2017–2019. Research on "oral health and quality of life" has been identified as core research area in RPD-related research. RPD research on digital dentistry and new framework materials is anticipated to increase in the future with the incorporation of research on quality of life.

Keywords: *Bibliometrics; citation analysis; removable prosthodontics; removable partial dentures.*

SCIENCE MAPPING OF RESEARCH CLUSTERS AND CORE RESEARCH AREAS IN REMOVABLE PARTIAL DENTURES

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Abstract

Science mapping helps provide a comprehensive review of a topic of interest based on the enormous scientific output in the academic literature. The study aims to identify research clusters, core research areas, and the highest impact terms based on the co-occurrence of keywords in removable partial dentures (RPDs) research for the past ten years, from 2012–2022. The search was done using the truncated search term "removable partial denture*" OR "removable prosthodontics*" based on the papers extracted from the Scopus database, and a bibliometric analysis tool was employed to automate keyword mapping. Data analysis and visualisation were done using Biblioshiny software (RStudio Desktop) and VOSviewer (Version 1.6.18). The search yielded 1043 articles following the refinement criteria. Data was cleaned to remove duplication and exclude irrelevant topics, leaving 888 documents from 114 journals to be analysed. From the 679 keywords extracted, six clusters were identified, enabling researchers to find research clusters: cluster 1 (predominantly complete dentures and shortened dental arches), cluster 2 (clasp in relation to materials), cluster 3 (latest technologies in RPDs fabrication), cluster 4 (implant-related), cluster 5 (quality-of-life (QoL)) and cluster 6 (abutment teeth). For the year 2012–2022, further analysis reveals that "polyetheretherketone (PEEK)", "3D-printing", and "systematic review" were identified as the top three high-impact terms based on the annual citation and annual normalised citation scores. Research on "implant" and "oral health QoL" has been identified as primary core research areas in RPDs-related research from 2012–2017, while "CAD-CAM", "3D-printing", "clasp" and "PEEK" emerged as new areas of interest among researchers in 2018–2022. PEEK has been identified as the highest impact term for the past ten years, highlighting the possible future research interest in RPDs-related research. Incorporating digital technologies in RPDs fabrication using high-performance polymers as materials is expected to increase in the future.

Keywords: Bibliometric Analysis, High-Impact Terms, Removable Partial Denture, Prosthodontics, Science Mapping

Introduction

A bibliometric study helps provide a comprehensive review of a topic of interest based on the enormous amounts of scientific output in the academic literature (1, 2). Science mapping is a visual representation of bibliometric data that allows researchers to explore the structure and dynamics of scientific knowledge and gain a comprehensive understanding of the emerging research patterns in a specific field (2–4). It reveals relationships,

patterns, clusters, and trends in scientific literature by employing techniques such as co-occurrence word analysis, co-citation analysis, and network visualisation (1, 5).

In recent years, the field of science mapping has gained significant attention due to the increasing need for systematic and objective analysis of scientific research domains. Several tools have been developed to facilitate the analysis of complex landscapes of scientific research domains, such as

Publications



Poly-Ether-Ether-Ketone (PEEK) Removable Partial Dentures: A Scoping Review

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To link to this article: <https://doi.org/10.21315/aos2024.1902.RV01>

(Note: Journal Admin will provide the final DOI)

ABSTRACT

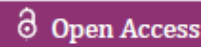
This scoping review aims to comprehensively assess the existing evidence from both clinical and in vitro studies concerning removable partial dentures (RPD) made from PEEK to identify current research gaps and enhance the understanding of PEEK's viability as a material for RPD. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) extension for scoping reviews was applied. A search was made using PubMed, Web of Science, Elsevier's Scopus, ProQuest and Springer Link databases for articles in the English language up to November 2023, focusing on case reports, clinical, and in vitro studies. A total of 33 studies were included in the analysis, which consisted of 4 case reports, 6 clinical studies, and 23 in vitro studies. Clinical studies predominantly examined patient satisfaction post-PEEK RPD insertion, framework accuracy, dimensional changes in residual ridges, and fungal/bacterial adhesion to PEEK. In vitro studies emphasized retentive force clasps (12 studies), accuracy and fitness (5 studies), material staining effects (3 studies), and diverse surface treatments (3 studies). The current body of evidence reveals a scarcity of clinical studies investigating PEEK as an RPD framework. In vitro studies primarily focused on assessing material retentive forces, with limited attention given to accuracy, surface treatment, and staining of denture base materials. Future research should address these gaps, exploring aspects such as adhesion and biofilm formation (e.g. *Candida albicans*) on RPD surfaces. Rigorous, well-designed clinical trials and expanded in vitro investigations are essential to establish PEEK RPD as definitive prostheses for partially edentulous patients.

Keywords: Framework; PEEK; poly-ether-ether-ketone; removable partial denture; scoping review.

Publications

IIUM Journal of Orofacial and Health Sciences (2025) 6(1): 141-146

TECHNICAL REPORT



Digital fabrication of flanges in removable partial dentures: a step-by-step workflow

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Abstract

The fabrication of flanges in removable partial dentures (RPD) traditionally entails labour-intensive manual manipulation of materials such as wax to sculpt and shape the flanges according to the patient's oral anatomy. This method requires a high level of skill and precision from dental technicians to ensure the final prosthesis fits comfortably and functions effectively. While most RPD framework designs are now executed digitally, the arrangement of artificial teeth and flanges often remains a manual process. This is primarily due to the scarcity of suitable software capable of designing flanges using computer-aided design (CAD) technology. This report addresses this challenge by presenting an alternative approach to flange design using the CAD software of 3Shape Dental System. By utilizing the software's function for custom tray design, we developed the flanges with the aid of abutment teeth, artificial teeth and framework, thereby improving the accuracy of gingival anatomy in flange fabrication.

Keywords: *computer aided design, dental technique, flanges, removable partial denture*

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Introduction

In recent years, there has been a significant transformation in the fabrication of dental prostheses with the widespread adoption of digital technologies. Despite these advancements, the fabrication of removable partial dentures (RPD) using digital techniques is still evolving (Akl & Stendahl, 2022; Piao *et al.*, 2022). The digital design process for RPD utilizes computer-aided design (CAD) software, which integrates patient-specific data obtained from intraoral scans or digital impressions (La Russo *et al.*, 2023). However, due to the diverse shapes

and irregularities of RPD parts (such as major and minor connectors, rests, clasps and base plates), creating a 3D design for the framework is often challenging and time-consuming. Additionally, a notable gap exists in current computer-aided design (CAD) software, which is the lack of dedicated functions and commands for designing flanges within RPD frameworks.

Flanges, which are extensions of the denture base are crucial components of RPD, providing support, stability, and retention for the prosthesis (Mousa *et al.*, 2021). Their proper design is essential for the functionality and comfort of the patient. Yet,

Evolving research on periodontal health of abutment teeth in removable partial dentures: A Scopus-based bibliometric analysis

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Abstract:

With partial edentulism prevalent among aging populations retaining natural teeth, understanding the relationship between removable partial dentures (RPDs) and abutment teeth periodontal health is crucial. To provide a bibliometric analysis of research trends on periodontal considerations of abutment teeth in RPDs, highlighting key publications, research clusters, and influential keywords from 1945 to 2024. An advanced search of Elsevier's Scopus database was conducted, extracting data such as publication titles, years, citations, journals, countries, and keywords. Bibliometric analysis and network visualizations were generated using BibPulse and VOSviewer software. The annual growth rate of studies on periodontal consideration of abutment teeth in RPDs was 2.38%. The Journal of Prosthetic Dentistry had the most publications and citations, while the Journal of Periodontology held the highest average and normalized citations, signifying its impact. Highly cited articles were predominantly clinical studies. Geographical analysis showed that the United States, Japan, and Germany had the highest research output, while Sweden, Switzerland, and Germany led in average citations per document, highlighting Europe's strong influence in this research area. The VOSviewer map identified nine distinct research clusters covering various aspects of prosthodontics, including material innovations, prosthetic design, patient quality of life, clinical assessments, complications, and advanced technologies. High-impact terms included "longitudinal study," "crowns," and "periosteal value" based on average citations, while "PEEK" leads in average normalized citations, indicating its growing influence. Periodontal considerations are central to research on abutment teeth in RPDs, highlighting the need for comprehensive, long-term evaluations of periodontal health and abutment teeth stability.

Key words:

Abutment teeth, bibliometric analysis, periodontal, removable partial denture

INTRODUCTION

The relationship between abutment teeth and removable partial dentures (RPDs) is a critical area of research in prosthodontics and periodontology, as the long-term success of RPDs heavily relies on the condition of the abutment teeth.¹ In clinical practice, abutment teeth serve as key support structures for RPDs, but their stability is often influenced by their periodontal health.²⁻³ Compromised periodontal health can weaken the support provided by abutment teeth, increasing the risk of mechanical failure or further teeth loss. This highlighted the need for ongoing evaluation and monitoring of both abutment teeth and periodontal status in patients receiving RPDs, as their interaction directly impacts the overall success of the treatment.⁴⁻⁵

Recent studies have explored various aspects of the abutment-RPD relationship, such as the effects of RPD wear on periodontal conditions,⁶⁻⁸ the treatment outcomes and survival rates of abutment teeth,⁹⁻¹¹ and the need for innovative

RPD designs and materials to minimize adverse impact on the abutment teeth.¹² It was suggested that while RPDs can be a viable treatment option for the partially edentulous patient, its long-term use can lead to unwanted consequences for the abutment teeth if not managed properly. Studies on abutment teeth in RPDs typically include an evaluation of periodontal health, as the condition of the periodontal tissues plays a crucial role in

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Publications

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ORIGINAL ARTICLE

ACP AMERICAN COLLEGE OF PROSTHODONTISTS
Your smile. Our specialty.

Framework material and design influence on biomechanical behavior of removable partial dentures: A finite element comparison of polyetheretherketone and cobalt-chromium

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Abstract

Purpose: This study evaluated the biomechanical impact of major connector designs and framework materials, polyetheretherketone (PEEK) and cobalt-chromium (CoCr), on deformation and mechanical stress distribution in the framework, periodontal ligament (PDL), and supporting mucosa through finite element analysis (FEA).

Materials and Methods: Intraoral data from a patient were obtained via cone beam computed tomography and a master model scan. Two removable partial denture (RPD) designs were modeled: a lingual plate and a lingual bar. A uniform pressure was applied bilaterally, producing a force of 120 N on each side. Deformation and stress distribution were analyzed using ANSYS Workbench FEA.

Results: For PEEK frameworks, the bar design reduced deformation in the framework and mucosa compared with the plate design but produced 25% higher PDL deformation. von Mises stress within the framework increased by 24% with the bar, while PDL stress increased by 58%, and mucosal stress decreased by 84%. In CoCr frameworks, the bar design similarly reduced framework and mucosal deformation, while PDL deformation showed minimal difference (9% lower with the plate). Unlike PEEK, the CoCr bar design reduced von Mises stress across all structures by 23%–57% compared with the plate.

Conclusions: The optimal major connector design is material-specific. For PEEK RPD, a bar design may be considered for patients with metal sensitivity and strong abutment teeth. In contrast, a plate design may be indicated for cases with periodontally compromised abutments with good residual ridges. In CoCr RPD, the bar design offers superior stress distribution, whereas the plate may be reserved for cases with strong abutments and good ridge support.

KEYWORDS

biomechanical, cobalt-chromium, finite element analysis, polyetheretherketone, removable partial denture

In Kennedy Class I situations, the lack of posterior abutments poses significant biomechanical challenges for removable partial dentures (RPDs). The terminal abutment teeth are subjected to substantial mechanical stresses during mastication because the components of the RPD, such as rests and clasps, are typically placed on them. The periodontal ligament (PDL), which acts as a cushion between the tooth and the surrounding bone, plays a critical role in absorbing and

distributing these mechanical stresses. Similarly, the mucosa underlying the denture base serves as a supportive, load-bearing structure, helping distribute functional forces to the underlying bone. However, due to the differences in the displaceability of the PDL of the terminal abutment teeth and the soft tissue over the distal edentulous ridge, rotational movement of the RPD often occurs under functional loads.^{1,2} This rotation amplifies the torque applied to the terminal

AUTHOR'S PROFILE



Dr. Nor Faharina Abdul Hamid obtained her Bachelor of Dental Surgery in 2007 from University of Malaya and Master of Restorative Dentistry in 2015 from Universiti Sains Malaysia. She obtained the Fellowship of the Royal Australasian College of Dental Surgeons in 2015. Her research interests include removable prosthodontics, dental material and dental education. She has published several peer-reviewed articles in national and international journals and has presented her work at multiple scientific conferences. Currently, she is actively involved in clinical practice, undergraduate and postgraduate teaching, and research in prosthodontics.

LIST OF PUBLICATIONS/PROCEEDINGS

- Hamid, N.F.A, Ariffin, F, Ahmad R. A Bibliometric Analysis of Removable Partial Denture-related Research in Dentistry, *Archives of Orofacial Sciences* 2023. 18 (2) : 103-124
- Hamid, N.F.A, Ahmad R, Ariffin, F, Shuib S. Science Mapping of Research Clusters and Core Research Areas in Removable Partial Dentures. *Journal of Health and Translational Medicine*, 2024 (JUMMEC): 9-15
- Hamid, N.F.A, Ahmad R, Ariffin, F, Shuib S. Poly-Ether-Ether-Ketone (PEEK) Removable Partial Dentures: A Scoping Review, *Archives of Orofacial Sciences* 2024, 19 (2) : 103-124

- Hamid, N.F.A, Yacob N, Ahmad R, , Shuib S. Abutment teeth as guidance to design flange in removable partial denture: A digital technical workflow. *IIUM Journal of Orofacial and Health Sciences*. 2025 Feb 28;6(1):141-6.
- Hamid, N.F.A, Adam, F.A, Ahmad R, Ariffin, F, Shuib S. Evolving Research on Periodontal Health of Abutment Teeth in Removable Partial Dentures: A Bibliometric Analysis *Journal of Indian Society of Periodontology*, 29(1), .6-13.
- Hamid, N.F.A, Ahmad R, Ariffin, F, Shuib S. Publication Trends in Removable Partial Dentures Research from 1948-2022, *Abstracts Proceedings. Malaysian Dental Journal* 2025; 48(2):130
- Hamid, N.F.A, Ahmad R, Izra'ai, S.I, Shuib S, Ariffin, F, Baba, N.Z. Framework material and design influence on biomechanical behavior of removable partial dentures: a finite element comparison of polyetheretherketone and cobalt-chromium, *Journal of Prosthodontics* 2026; 1-9

CONFERENCES/ PRESENTATIONS

- Hamid, N.F.A, Ahmad R, Ariffin, F, Shuib S. Science Mapping of Research Clusters and Core Research Areas in Removable Partial Dentures, 2023 International Association for Dental Research Malaysian Section (Second place, Senior Catogery for Poster Presentation), 9 September 2023
- Hamid, N.F.A Three Minute Thesis (3MT) Competition (First place, Faculty Level), 3 May 2024
- Hamid, N.F.A Three Minute Thesis (3MT) Competition (University Level), 21 May 2024
- Hamid, N.F.A, Ahmad R, Ariffin, F, Shuib S. Publication Trends in Removable Partial Dentures Research from 1948-2022 (Oral presentation), 15th Malaysian Association for Prosthodontics (MAP) Scientific Conference & Annual General Meeting , 4-5 July 2025.

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MAKLUMAT BAHAN

JUDUL BAHAN/ TITLE: THE EFFECT OF METAL- AND POLYMER-BASED REMOVABLE PARTIAL DENTURE FRAMEWORK ON THE PROGNOSIS OF TERMINAL ABUTMENT TOOTH