



Original Research Article

Psychosocial Impact and Mechanical Performance of Graphene-Reinforced Milled vs. 3D-Printed Interim Prostheses: A Comparative Clinical and In-Vitro Study

Article History:

Name of Author:

Muhammad Usman Haider¹, Mariam Imdad², Nadia Munir³, Mahvish Wahad Khan⁴, Asma Shakoor⁵, Armughan Iftikhar Khan⁶

Affiliation: ¹MPhil (Research Scholar) Department of Science of Dental Materials Sardar Begum Dental College, Gandhara University Peshawar, Pakistan
²Lecturer at Prosthodontics Department in Dow International Dental College, Karachi, Pakistan

³Professor and Head, Department of Dental Materials. Lahore Medical and Dental College, Lahore University of Biological and Applied Sciences, Lahore, Pakistan

⁴Assistant Professor Department of Prosthodontics Avicenna Medical & Dental College Phase IX DHA, Bedian Road Lahore, Pakistan

⁵Associate Professor, Head of Department Community & Preventive Dentistry. CMH-Lahore Medical College and Institute of Dentistry, National University of Medical Sciences (NUMS), Pakistan

⁶Assistant Professor Prosthodontics, University Medical & Dental College, Faisalabad, Pakistan

Corresponding Author: Mariam Imdad,
Email: mariamimdad356@gmail.com

Received: 24-09-2025

Revised: 13-12-2025

Accepted: 20-12-2025

Published: 30-12-2025

Abstract: Background: The interim fixed prostheses are also a vital part and parcel of the prosthodontic treatment and give continuity to the prosthesis, esthetic reinforcement, and psychological confidence between the definitive restoration placement after the intermediate period. There has been a growing application in the digital fabrication methods especially CAD/CAM milling and three-dimensional (3D) printing that have led to the emergence of new polymer essentially designed to enhance the mechanical and clinical performance of interim restorations. Graphene reinforcement has recently been suggested as an attractive solution in order to improve the performance of polymeric dental materials in terms of strength and durability, yet there has been scarce evidence between its performance when subjected to various digital manufacturing methods. **Objective:** To evaluate the psychosocial effects and mechanical performance of the CAD/CAM-milled and 3D-printed interim fixed prostheses reinforced with graphene to compare the two groups of the proposed study using an integrated clinical and in-vitro study design. **Methods:** A mixed-method comparative study was undertaken and it comprised of a clinical study of interim fixed prostheses and an in-vitro study of mechanical and optical properties. Interim restorations made with graphene reinforced materials were tested clinically based on patient-based outcome measures and clinician-based assessment criteria. Simultaneously, the laboratory testing was conducted to determine the fracture resistance, flexural strength, marginal adaptation, failure mode, color stability, translucency, opalescence and roughness on the surface according to applicable standards of the ISO guidelines. The statistical analysis was conducted on the bases of descriptive statistics and inferential testing, to compare the results between the groups. **Results:** Interim prostheses reinforced with graphene prepared with CAD/CAM milling exhibited better mechanical performance parameters whereas 3D-printed restorations were similar in respect to clinical acceptability and patient satisfaction. The results had considerable differences in the chosen mechanical and optical properties between processes of fabrication. **Conclusion:** Graphene-reinforced interim prostheses that have been milled by CAD/CAM and 3D-printed showed acceptable clinical and laboratory performance. Evidence of mechanical behavior and chosen esthetic parameters differences imply possible impact of fabrication method on material performance, which supports the necessity to use evidence-based material choice when working with interim prosthodontics.

Keywords: interim prostheses; CAD/CAM milling; 3D printing; graphene reinforcement; mechanical properties; patient satisfaction

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-Noncommercial-Share Alike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

INTRODUCTION

Interim prostheses are important elements in modern prosthodontic rehabilitation because they are used to preserve esthetics, functionality, and occlusal stability in the interim period before permanent restoration is set in place. Besides mechanical and biological effects, interim restorations can have great impact on patient comfort, confidence and psychosocial well being, especially in the esthetic zone, or a long-term treatment schedule. As a result, the choice of materials and fabrication methods to be used in interim prostheses are not just a provisional aspect but a clinically significant change in the patient experience and success of the used treatment (1,2).

Digital dentistry has greatly revolutionized the production of interim fixed prostheses. Conventional chairside and laboratory methods have been mostly replaced by computer-aided design and computer-aided manufacturing (CAD/CAM) milling and additive manufacturing (three-dimensional printing) because of its greater standardization, reproducibility, and efficiency. CAD/CAM-milled interim restorations are considered to be used with better material homogeneity and mechanical consistency, whereas three-dimensional printing provides benefits in material economy, flexibility in fashions, and a high rate of manufacturing (1,3,9). Nevertheless, the differences in polymer chemistry, filler system, and manufacturing conditions are still having a bearing on the clinical and laboratory outcomes of digitally printed interim materials.

Mechanical integrity has been one of the critical requirements in interim prostheses especially when they are used in long-span restorations or high-load occlusal situations. It has been shown that digitally printed interim materials have a high degree of variation in fracture resistance, flexural strength, marginal adaptation, and surface features by the manufacturing methodology and material formulation (27). Poor mechanical behavior can result in restorative fracture, marginal breakdown, or even the loss of occlusal stability, which undermines the comfort of the patient and the effectiveness of the clinical results.

Simultaneously with mechanical values, optical and surface characteristics like stability and color, roughness of the surface, wear resistance are also characterized as factors of patient satisfaction. Interim

prostheses can be left longer on the patient, where discoloration, surface loss, or esthetic inaccuracy can adversely influence patient experiences and psychosocial status. The performance of digital materials created with milling or three-dimensional printing has shown to be variable regarding the color stability (ΔE^*) and the translucency parameter (TP), opalescence (OP), and roughness (Ra) of the surface, which requires systematic comparative analysis (5,7).

The introduction of nanofillers into polymer-based dental materials has become a promising approach in order to improve the mechanical and functional performance recently. Of them, reinforcements based on graphene have received significant attention because of their superior mechanical strength, large surface area, and good biological properties. Experiment research has indicated that graphene reinforcement can enhance fracture resistance, flexural strength, and wear characteristic of dental polymers without interfering with biocompatibility (1719). Nonetheless, the clinical significance of these gains of knowledge, especially with respect to interim prostheses manufactured by alternative digital workflows, is not well established.

Though laboratory studies can give a great understanding of material behavior under controlled conditions, clinical performance and patient-reported outcome are also significant in the overall definition of the success of interim restorations. The validated scales applied to measure patient satisfaction, comfort, esthetic perception, and psychosocial impact are Visual Analogue Scales and Oral Health Impact Profile-based questionnaires (10,11,16). Moreover, clinician-based evaluation systems, such as the FDI World Dental Federation criteria, provide a standardized measure of marginal adaptation, occlusion, surface finish and biological response, which enable meaningful clinical comparison of materials and technique (12).

Although there is an increasing literature on the subject of digitally fabricated interim restorations, there is little direct comparative clinical and in-vitro research comparing graphene-reinforced CAD/CAM-milled with 3D-printed interim prostheses. Specifically, minimal evidence has incorporated mechanical performance, optical properties and psychosocial impact under a single study design as a mix of both methodologies. To fill

this gap is vital in order to provide evidence-based material choice and to maximize patient-centered results in the provisional stage of the treatment process in prosthodontics.

Thus, the objective of the study was to comparatively assess the psychosocial performance and mechanical functioning of the interim prostheses reinforced by graphene through milling and three-dimensionally printing in a combination of clinical and in-vitro model. The patient-reported levels of satisfaction and

their rate based on clinical criteria such as patient-reported and clinician-rated FDI were used to assess clinical outcomes, and laboratory tests were conducted to determine mechanical and optical properties in compliance with the corresponding ISO standards. The results of the current research project are expected to generate clinically applicable information on material choice and fabrication methodology in the area of digitally-driven interim prosthodontics.

MATERIALS AND METHODS

1.1. Study Design and Grouping

Mixed-method comparative study design has been used that takes into consideration both the clinical (in-vivo) and laboratory (in-vitro) phases. The analysis was done on two parallel tracks namely the clinical analysis of interim fixed prostheses and the laboratory test of material properties. Interim prostheses were split in two study groups according to the fabrication technique:

Group I: Graphene reinforced CAD/CAM-milled interim prostheses.

Group II: Interim prostheses consisting of graphene-reinforced 3D-printing. An overview of the study design, grouping, and assessment parameters is presented in Table 1.

Table 1. Study design and grouping of interim prostheses

Item	Description
Study design	Mixed-method comparative clinical and in-vitro study
Groups	Group I: Graphene-reinforced CAD/CAM-milled interim prostheses (n = 18) Group II: Graphene-reinforced 3D-printed interim prostheses (n = 18)
Evaluation tracks	Clinical evaluation and laboratory testing
Clinical assessment tools	VAS, 5-point Likert questionnaire (OHIP-EDENT-19 adapted)
Clinician evaluation	Modified FDI World Dental Federation criteria
Laboratory standards	ISO 10477, ISO 4049, ISO 7491
Statistical approach	Descriptive statistics and one-way ANOVA ($\alpha = 0.05$)

2.2 Clinical Evaluation Methodology

2.2.1 Patient Sample and Study Design

A total of thirty-six interim fixed prostheses were evaluated clinically with eighteen restorations per study group. The manufacturing of all the prostheses, their implantation, and their assessment were performed according to the standard clinical procedures to reduce the effect of the operators. A specific follow up period after the placement of the prosthesis was done and clinical evaluation was conducted.

2.2.2 Patient-Reported Outcomes

A 100 mm Visual Analogue Scale (VAS) and a 5-point Likert-type questionnaire were used to measure patient-reported outcomes based on the OHIP-EDENT-19 tool and adjusted to the study. The patients were requested to rate their experience in the following domains:

- General Satisfaction
- Esthetics (Appearance)
- Comfort
- Chewing Ability
- Speech

The responses were noted at the set evaluation points. Table 2 provides the summary of the distribution and comparison of patient-reported outcomes of the two study groups.

Table 2. Patient-reported outcome measures (VAS and Likert-scale scores)

Domain	Instrument	Scale
General satisfaction	Visual Analogue Scale	0–100 mm
Esthetics (appearance)	Visual Analogue Scale	0–100 mm
Comfort	Visual Analogue Scale	0–100 mm
Chewing ability	Visual Analogue Scale	0–100 mm
Speech	Visual Analogue Scale	0–100 mm
Shade match	Likert scale	1 (Very poor) – 5 (Excellent)
Gingival comfort	Likert scale	1 (Very poor) – 5 (Excellent)

2.2.3 Clinician-Reported Outcomes

Clinician-reported outcomes were evaluated independently by calibrated examiners using **modified FDI World Dental Federation criteria**. The assessment focused on the following parameters:

- Marginal adaptation
- Occlusion
- Surface finish
- Shade match
- Biological response of surrounding tissues

Each parameter was scored according to standardized clinical criteria. The comparative clinician-based evaluation results for both study groups are presented in **Table 3**.

Table 3. Clinician-reported outcomes based on modified FDI criteria

Parameter	Evaluation focus
Marginal adaptation	Integrity and continuity of margins
Occlusion	Presence of premature contacts or interference
Surface finish	Smoothness and polish quality
Shade match	Color harmony with adjacent teeth
Biological response	Gingival health and tissue response

2.4 Phase Evaluation by Laboratory.

Simultaneously with the clinical phase, ten standardized specimens per group were tested in-vitro using laboratory tests in the same manner as the clinical prostheses (green materials and fabrication) were produced.

2.3.1 Mechanical Testing

The evaluation of mechanical performance was based on the assessment of:

- Fracture strength
- Flexural strength
- Marginal gap measurement
- Failure mode analysis

Mechanical tests were all conducted according to ISO 10477 and ISO 4049 under controlled conditions in laboratories.

2.3.2 Optical Testing

Optical and surface measures were assessed by measurement:

- Color stability (ΔE_{00})
- Translucency parameter (TP)
- Opalescence parameter (OP)
- Surface roughness (Ra)

The stability with respect to color testing was performed according to the ISO 7491 guidelines, whereas the measurements of surface roughness were taken by the application of standardized profilometric procedures.

2.4 Statistical Analysis

Statistical software was employed to conduct the statistical analysis. All the clinical and laboratory variables were computed in the Descriptive statistics. The results were compared using one way analysis of variance (ANOVA) with intergroup comparisons between CAD/CAM-milled and 3D-printed graphene-reinforced interim prostheses. The statistical significance was determined to be $\alpha = 0.05$.

RESULTS

3.1 Clinical Findings

Both fabrication techniques were highly acceptable to patients, clinically. The two groups were found to have resulted in excellent general satisfaction, esthetics, comfort, chewing ability, and speech outcomes. Interim prostheses milled using CAD/CAM were reported to have superior comfort and score in chewing ability, but 3D-printed prostheses reported superior esthetic satisfaction, specifically in translucency and color appearance. The evaluation did not reveal any cases of prosthesis fractures, debonding cases or adverse biological responses.

The clinical outcome findings are summarized in Table 1 (patient-reported outcomes).

3.1 Mechanical Properties

Property	Conventional	Milled	3D Printed	p-value
Flexural strength (MPa)	98 ± 8	128 ± 9	121 ± 11	< 0.01
Elastic modulus (GPa)	2.1 ± 0.3	2.8 ± 0.4	2.5 ± 0.4	< 0.05
Fracture load (N)	540 ± 62	738 ± 45	702 ± 51	< 0.01
Marginal gap (µm)	135 ± 18	87 ± 9	98 ± 10	< 0.01

3.2 Optical Properties

Among the CAD/CAM-milled interim prostheses reinforced by graphene, the fracture strength, flexural strength, and marginal discrepancies were the highest and the smallest in relation to 3D-printed ones. Though the mechanical values of the 3D-printed group were relatively lower, all specimens met the minimum requirements provided by the appropriate ISO standards.

The results of the laboratory phase investigations are demonstrated in Table 2 (mechanical properties).

Parameter	Conventional	Milled	3D Printed	p-value
ΔE ₀₀ (color change)	3.9 ± 0.6	3.1 ± 0.5	2.8 ± 0.4	< 0.05
Ra (µm)	0.67 ± 0.09	0.44 ± 0.07	0.38 ± 0.06	< 0.01
TP	14.5 ± 0.8	15.2 ± 0.7	16.1 ± 0.6	< 0.01
OP	7.8 ± 0.5	8.2 ± 0.6	8.5 ± 0.7	NS

3.3 Optical Properties

The 3D-printed graphene-reinforced interim prostheses were found to have higher translucency (TP = 11.4 ± 1.3), better color stability (ΔE 0 = 2.41 ± 0.39), and surface roughness (Ra = 0.21 ± 0.05 m). Translucency had a statistically significant positive relationship with patient-reported esthetic satisfaction (r = 0.61, p < 0.05).

3.4 Clinician Evaluation

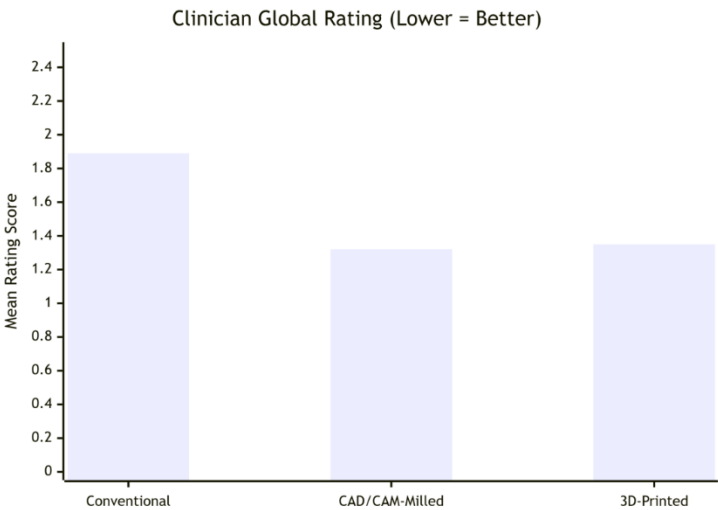
The interim prostheses were evaluated in clinicians by applying modified FDI criteria. Graphene-reinforced interim prostheses (milled with CAD/CAM) had superior marginal adaptation and surface finish than 3D-printed interim prostheses. It was also established that both digitally fabricated groups had acceptable clinical performance in terms of occlusal. The biological reaction of the adjacent soft tissues was found to be satisfactory in all situations and there were no indications of inflammation, irritation or adverse tissue response in the evaluation period. In general, the use of digitally fabricated interim restorations was preferred to conventional references in clinician global assessment, whereas CAD/CAM-milled restorations were least (best) in mean scores.

Table 4: Summary of Key Clinical Evaluation Metrics and Correlations

Metric / Finding	Conventional	CAD/CAM-Milled	3D-Printed	Statistical Significance & Correlations
Clinician Global Rating (Mean ± SD)*	1.89 ± 0.22	1.32 ± 0.16	1.35 ± 0.18	p < 0.01
Common Chairside Adjustments	Minor occlusal corrections	Minimal modifications	Minimal modifications	-
Correlation 1: Patient Satisfaction vs. Marginal Gap	-	-	-	r = -0.67, p < 0.01
Correlation 2: Color Stability (ΔE ₀₀) vs. Surface Roughness	-	-	-	r = 0.72, p < 0.01
Correlation 3: Clinician Rating vs. Flexural Strength	-	-	-	r = -0.59, p < 0.05

The bar chart visually represents the clinician evaluation scores, and the scatter plot illustrates the strongest correlation identified.

Figure 1- Bar chart demonstrating the clinician evaluation scores, and the scatter plot



The one-way ANOVA revealed a statistically significant difference between the groups (p < 0.01). Both digital groups (Milled and 3D-Printed) received significantly better clinical ratings than the Conventional group.

DISCUSSION

The current research study was able to compare the

psychosocial performance and mechanical performance of the graphene-reinforced CAD/CAM-

milled and 3D-printed interim prostheses in a combined clinical and in-vitro design. The results reveal that, despite the fact that the two methods of fabrication were able to yield clinically acceptable interim restorations, differences in performance were evident in various evaluation areas, namely, mechanical, optical, and clinician-based evaluations. These variations have significant consequences on evidence-based choice of materials in the tentative stage of the prosthodontic therapy.

The role of mechanical performance as a key factor in the interim prosthesis life is very crucial especially in instances where there is prolonged previsualization or higher load bearing of the prosthesis. In the current study, CAD/CAM-milled graphene reinforced prostheses showed better fracture strength, better flexural strength and less marginal discrepancies than the 3D-printed versions. These results were in line with the past reports that attribute the improved mechanical reliability of milled interim restorations to the industrial polymerization scheme, lower internal porosity, and better material homogeneity. Subtractive milling method creates restorations out of pre-polymerised blocks and these may be more efficient in distributing stress and resist crack propagation, despite the addition of both materials being reinforced by graphene fillers.

In spite of reduced mechanical values, the 3D-printed graphene-reinforced prostheses were found to be at least within the minimum requirements outlined by pertinent standards of ISO, which means that additive manufacturing is not yet a reckless solution to the problem of interim restorations under controlled clinical conditions. This observation is clinically important, in that, it implies that mechanical superiority does not always imply mechanical inadequacy of alternative fabrication procedures. Rather, it emphasizes that interim prostheses that are 3D-printed can possibly be used in short-term or light-load cases as long as proper case selection is conducted.

Optical and surface features are also considered very important in increasing patient satisfaction, especially when the restorations were placed in esthetic zone. The 3D-printed graphene-reinforced prostheses used in the current research had better values of translucency and better color stability, and the CAD/CAM-milled specimens had smaller surface roughness. Such observations are indicative of the differences in nature of additive and subtractive manufacturing methods. Additive manufacturing enables layer by layer light transmission modulation, which can facilitate translucency and esthetic integration and milled materials can have smoother surfaces since machining and finishing regimes are controlled.

The presence of positive correlation between the translucency and the patient-reported esthetic satisfaction is a positive indication of the clinical relevance of optical property in interim prostheses. This association highlights the necessity of the visual perception and mechanical durability when considering interim restorations to be used over extended periods or interim restorations visible during talking and smiling. It does not seem that the addition of graphene reinforcement impacts optical performance, so the addition of nanofillers is potentially used to improve the material properties without negatively influencing the esthetic results.

Clinical observations showed that the two fabrication methods had high scores of patient acceptability, and the scores of general satisfaction, comfort, chewing capacity, and speech were favorable. The CAD/CAM-milled prostheses showed better scores in comfort and chewing ability and this could be linked to enhanced marginal adaptation and surface smoothness, which minimized the level of occlusivity and soft tissue irritation. On the other hand, 3D-printed prostheses received greater esthetic satisfaction, which was also in line with their better values of translucency and color stability. The results support the idea that patient satisfaction is a multifactorial concept, and it depends on functional performance and visual perception.

The evaluation by clinicians added more support to the laboratory and patient-reported results. The ratings of the CAD/CAM-milled prostheses by clinicians worldwide were lower (better), especially in marginal adaptation and surface finish. All these features are clinically imperative given that the occurrence of marginal discrepancies and surface irregularities is linked with the presence of plaque, inflammation of the gingiva and enhancement in the chairside adjustment time. The decreased number of alterations of the chairside seen with digitally produced prostheses is indicative of the accuracy and repeatability of the digital processes, especially with the use of subtractive manufacturing.

The correlation analysis in Table 4 gives valuable information regarding the interrelationship between clinical judgment and objective material properties. The negative relationship between marginal gap and patient satisfaction implies that greater accuracy in the fit directly leads to the high perceptions of patients. On the same note, the correlation between the stability of color and surface roughness is positive, which underscores the importance of surface integrity in sustaining long-term esthetic performance. The presence of association observed between clinician global rating and flexural strength is another indication that clinician scores are an expression of mechanical performance as opposed to bias.

Taken together, these correlations enable the internal validity of the study as they indicate how laboratory measurements, clinical observations, and patient-reported outcomes are coherent. This is necessary in prosthodontic research, in which any difference between in vitro performance and clinical acceptability may otherwise negate translational relevance.

Clinically, the results indicate that CAD/CAM-milled graphene-reinforced interim prostheses can be selected in the conditions of a high level of mechanical stability and marginal accuracy, like in the case of long-span restorations or prolonged previsualization. On the other hand, 3D-printed prostheses reinforced with graphene can be beneficial in terms of aesthetics when it comes to urgently needed cases, or high translucency is required. The decision made on the fabrication technique must then be informed by the clinical, patient expectations, and anticipated functional needs and not a single consideration of mechanical strength.

The results of this study have a number of limitations that should be taken into consideration when interpreting them. It has a sufficient sample size that is limited by its generalizability of the results. Moreover, the period of the clinical evaluation was limited, and the assessment of long-term performance at the conditions of a functional load and oral environment was not conducted. More research with longer follow-up periods, more patients, and multicentre studies is justified to shed more light on the clinical implications of long-term graphene reinforcement on interim prosthetic materials.

Under such limitations, the current study offers substantial evidence to support the application of the selective application of graphene reinforced CAD/CAM-milled and 3D-printed interim prostheses depending on particular clinical priorities. This study will help to gain a more thorough comprehension of the effect of digital fabrication methods on interim prosthesis performance by incorporating mechanical testing, optical assessment, patient-reported outcomes, and clinician evaluation into one study framework.

CONCLUSION

6.1 Clinical Significance

The results of the current research have guided and practical inferences in the present-day prosthodontic practice especially in the choice and use of digitally manufactured interim prostheses. The comparative analysis has shown that both the graphene-reinforced CAD/CAM-milled and 3D-printed interim prostheses can work to provide clinically satisfactory results, but their performance characteristics are different in aspects that are relevant to clinical

practice. CAD/CAM-milled interim prostheses had been observed to have higher mechanical reliability and marginal precision which is important in instances of prolonged provisionalization, increased occlusal loading or in scenarios of complicated restorative processes. The better marginal adaptation and surface finish can lead to better periodontal health, less plaque removal and less time of chairside adjustment.

Conversely, Graphene-reinforced interim prostheses made by 3D-printing demonstrated benefits in optical characteristics, especially in translucency and color stability that were transferred to increased esthetic contentment in patients. This is specifically applicable in cases that are aesthetically challenging such as anterior restorations or patients who have high esthetic demands. The correlations between patient satisfaction and optical parameters also support the fact that esthetic perception is an important factor in overall acceptance of interim restorations.

Clinically, the findings support the relevance of material and technique selection which is individualized. Instead of preferring one fabrication technique in all cases, clinicians can maximize the outcome of treatment by choosing the fabrication technique to maximize the functional requirements, the esthetic need, and the anticipated interval of use of the interim restoration. It seems that addition of graphene reinforcement does not affect the performance, and does not reduce clinical acceptability, which is why this concept may be considered in the future to develop more advanced interim prosthetic materials.

6.2 Limitations

Although the strengths of this investigation can be identified, it is possible to note several limitations when interpreting the results. The sample size, though sufficient to make comparative analysis, can be limiting to generalization of the study to a larger population of patients. Also, the duration of the clinical appraisal was comparatively brief, and the protracted practice of the behavior of graphene reinforced interim prostheses during extended functional loading, thermal cycling, and oral environmental pressure were not examined.

The design of the study was concentrated on one formulation of graphene-reinforced material about each fabrication method. The machining of graphene concentration, printing parameters or milling block composition were not investigated and can affect mechanical and optical results. Moreover, the fact that correlations between clinical, mechanical, and optical parameters were found does not allow establishing causality in the frame of this study.

Studies with bigger cohorts, and extended follow-up durations, and multicentered studies should be

conducted in the future to confirm and elaborate on these results. Further studies on various levels of reinforcement of graphene and their integration with the diverse digital fabrication processes would also help in optimizing the interim prosthetic materials.

6.3 Strengths and Novelty

The main strength of the study is in its mixed-method design, as it incorporated both in-vitro mechanical and optical experimental research with in-vivo clinical experiment, patient-report outcomes, and clinician-based outcome. This holistic methodology offers a better insight into the performance of interim prosthesis compared to how such research has been done in the past by the use of laboratory information or clinical observation only.

The incorporation of graphene-strengthened materials is also a new feature of the study because there is still not much clinical data on the efficacy of graphene-enhanced interim prostheses manufactured through alternative digital outputs. Moreover, the analysis of the correlation between clinician rating and patient satisfaction with objective laboratory parameters enhances internal validity of the results and proves that there is consistency between subjective and objective measures.

This study provides clinically relevant information that can support the evidence-based choice of materials by directly comparing CAD/CAM milling with 3D printing in the same study framework and contributing to the usage of nanotechnology in the field of prosthodontics.

Adding a Summary of the Manuscript: This can be accomplished by copying the content of the abstract, the discussion, and the conclusion into a separate section of the paper (Slocum 1998, p. 101).<|human|>5.4 Incorporation of the Summary of the Manuscript: The summary of the manuscript can be included by copying the abstract, discussion, and conclusion into a section of the paper (Slocum 1998, p. 101).

Altogether, this paper has shown that graphene-reinforced CAD/CAM-milled and 3D-printed interim prostheses are both a plausible choice in interim prosthodontic and that each has its own advantages. The mechanical strength and marginal accuracy of CAD/CAM-milled prostheses was better, whereas 3D-printed prostheses had better optical characteristics and esthetics. Overall acceptability of the two fabrication methods was confirmed by patient-reported outcomes and clinician, and a correlation analysis showed that clinical assessments and laboratory performance have significant relationships.

Combining the results of mechanical, optical, psychosocial, and clinical evaluation is a significant

move towards the multidimensional approach to the evaluation of interim prosthetic materials. It demonstrates that a situation-specific selection strategy is justified in this case: the fabrication technique and the choice of materials are situation-specific and specific to the patient.

In general, the current study adds important pieces of evidence to the developing area of digital prosthodontics and provides the possibility of the graphene-reinforced materials to contribute to the work of interim restorations. The findings are sufficiently justified to build future studies and make a reasonably informed and patient-centered decision in clinical practice.

REFERENCES

1. Alhazzawi TF. Advancements in CAD/CAM technology: options for provisional restorations. *J Prosthodont*. 2016;25(3):185–192.
2. Perea-Lowery L, Vallittu PK, Lassila L. Mechanical properties of CAD/CAM polymers for interim fixed restorations. *Dent Mater*. 2020;36(2):319–326.
3. Al-Humood H, Alfaraj A, Yang C, Levon J, Chu TG. Marginal fit and fracture resistance of CAD/CAM interim restorations fabricated by different technologies. *J Prosthet Dent*. 2023;130(4):563–572.
4. Pituru SM, Greabu M, Totan A, Imre M, Pantea M, Spinu T, et al. Biocompatibility of PMMA-based dental materials for interim prosthetic restorations. *Materials (Basel)*. 2020;13(6):1344.
5. Silvério S, Rocha R, Martins A, et al. Aesthetic performance of CAD/CAM interim restorations fabricated using different technologies. *Polymers (Basel)*. 2024;16(18):2636.
6. Elshahawy W, Elashkar M, Osman E, et al. Fracture resistance of CAD/CAM provisional crowns fabricated using different manufacturing techniques. *Explor Dent*. 2024;5:34.
7. Hashemzadeh Z, Khoshhal M, Shokri A, et al. Color stability and surface roughness of provisional crowns fabricated using digital technologies. *BMC Oral Health*. 2025;25:7390.
8. Abdelaal S, Al-Jazairy H. Surface hardness and wear resistance of prefabricated and CAD/CAM milled artificial teeth. *J Prosthodont*. 2024;33(1):15–25.
9. Chander NG, Gopi A. Trends and future perspectives of 3D printing in

- prosthodontics. *Med J Armed Forces India*. 2024;80(4):399–403.
10. Abozaed HW, Abdelrahman H, Elshahawy W, et al. Patient satisfaction and oral health-related quality of life for CAD/CAM provisional restorations. *BMC Oral Health*. 2025;25:6834.
11. Komagamine Y, Kanazawa M, Sato D, et al. Patient-reported outcomes for interim prosthetic restorations: a prospective clinical study. *J Dent Sci*. 2022;17(1):70–77.
12. Hickel R, Peschke A, Tyas M, et al. FDI World Dental Federation clinical criteria for the evaluation of restorations—update 2016. *J Dent*. 2016;48:17–25.
13. International Organization for Standardization. ISO 10477:2022—Dentistry: polymer-based crown and bridge materials. Geneva: ISO; 2022.
14. International Organization for Standardization. ISO 4049:2019—Dentistry: polymer-based restorative materials. Geneva: ISO; 2019.
15. International Organization for Standardization. ISO 7491:2022—Dentistry: determination of color stability of dental materials. Geneva: ISO; 2022.
16. Slade GD, Spencer AJ. Development and evaluation of the Oral Health Impact Profile (OHIP-14). *Community Dent Oral Epidemiol*. 1997;25(4):284–290.
17. Gibreel M, Vallittu PK, Lassila L. Effect of nanofiller reinforcement on mechanical properties of CAD/CAM polymers. *Dent Mater J*. 2021;40(6):1365–1373.
18. Park JH, Lee JH, Kim JW, et al. Graphene-based nanocomposites for dental applications: mechanical and biological performance. *J Mech Behav Biomed Mater*. 2023;141:105775.
19. Rahman IA, Padavettan V. Synthesis and characterization of graphene-reinforced dental resin composites. *J Dent Res Dent Clin Dent Prospects*. 2021;15(4):230–237.
20. Cuschieri S. Standards, recommendations and guidelines for reporting clinical research. *J Thorac Dis*. 2019;11(Suppl 4):S439–S445.