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Comparison of CAD/CAM and Conventional Techniques for Dental Restoration

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ABSTRACT

Background: The evolution of digital dentistry has transformed the process of restorative dentistry, with Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology proving to be a better option compared to conventional techniques for the fabrication of dental restoratives such as crowns, inlays, onlays, and veneers.

Objective: The objective of the present systematic review and meta-analysis was to compare the clinical performance, precision, efficiency, and longevity of CAD/CAM restorations and conventional methods.

Methods: The search strategy included a comprehensive search of various databases like PubMed, Scopus, and Cochrane, and 55 comparative studies from 2000 to 2025 were included. The results included marginal fit in µm, internal adaptation, fracture resistance, survival, chair time, and patient satisfaction.

Results: CAD/CAM restorations showed significantly better marginal fit, with a mean discrepancy of 62 to 80 µm (95% CI: 55 to 85 µm) compared to 110 to 150 µm (95% CI: 100 to 170 µm) for conventional restorations ($p < 0.001$), thus minimizing the risk of secondary caries and periodontal disease. Internal adaptation was improved by 40 to 60% in CAD/CAM restorations. Fracture strength was also better in milled ceramics compared to conventionally processed materials. Survival rates were similar or better at 5 years, at 94.5% for CAD/CAM and 91.2% for conventional, HR 0.88, 95% CI: 0.75 to 1.03. CAD/CAM technology reduced chairside time by 60 to 75% (1 to 2 hours vs. 2 to 3 weeks) and laboratory remakes by 50%. Patient satisfaction scores were 25 to 35% better because of single-visit procedures and improved esthetics.

Conclusion: CAD/CAM technology has proven to be superior to conventional methods in precision, efficiency, and mechanical properties, thus making it the gold standard in dental restoration.

KEYWORDS: CAD/CAM dentistry, dental restorations, conventional techniques, marginal fit, survival rate, digital workflow.

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INTRODUCTION

The burden of oral diseases worldwide is a major public health issue that affects a large number of the world's population, totaling nearly 3.7 billion individuals worldwide. Untreated dental caries of permanent teeth are the most common oral health problem. This is a clear indication that the need for restoration and prosthetics is a critical issue that needs to be addressed, especially among those who do not have access to dental care (Sadid-Zadeh, 2023).

The conventional restorative techniques, which involve manual impressions, wax-ups, lost-wax casting, and porcelain layering, have been the cornerstone of fixed prosthodontics for a long time but have some limitations, such as dimensional inaccuracy, which is mainly caused by shrinkage, polymerization contraction, and processing errors, as well as the various processing steps involved, which may result in errors (Vogler et al., 2023). The introduction of CAD/CAM technology in dentistry can be traced back to the 1970s, with clinical application commencing in the 1980s, owing to advancements in optical scanning, computer processing, and material science, which have improved the hardware and software of the technology, making it more precise and user-friendly (Zarina et al., 2017). CAD/CAM technology has greatly improved, allowing for a fully digital workflow, which eliminates errors, as well as allowing for chairside production, making the treatment time much shorter, as opposed to conventional techniques, which require multiple patient visits (Sadid-Zadeh, 2023).

CAD/CAM-assisted post-and-core restorations have shown superior accuracy of fit in comparative clinical evaluations ($p=0.022$) and significantly better feasibility of impression taking ($p < 0.001$) in comparison to conventional cast post-and-core procedures, thereby underlining the clinical benefits of the digital workflow for complex dental procedures (Vogler et al., 2023).CAD/CAM materials have shown better mechanical properties, i.e., better flexural strength, lower porosity, and better fracture toughness due to the industrialized production process that minimizes the occurrence of defects commonly observed in conventional materials (Rexhepi et al., 2023).Systematic evaluations of CAD/CAM materials have proved that they can be used for a wide range of dental procedures due to their clinical suitability for dental restoration and prosthetics, with materials such as monolithic zirconia and lithium disilicate having flexural strengths of over 1000 MPa and better performance in areas of high load, thereby surpassing the performance of conventional materials that tend to chip or delaminate (Rexhepi et al., 2023).

For interim fixed prosthodontic restorations, CAD/CAM materials such as PMMA, materials containing graphene, acetal resin, and polysulfone offer different grades of resistance to fracture. The materials containing graphene have shown promising results in terms of durability for interim fixed prosthodontic restorations (Calle Barros & Abril Ochoa, 2023). The constant improvement in CAD/CAM materials has helped prosthodontics in many ways. Hybrid ceramics and resin-based blocks have been introduced to the field of prosthodontics. These materials have shown better mechanical properties compared to the traditionally used feldspathic ceramics (Paulson, 2023).

Among the various methods of CAD/CAM fabrication technologies, 3D printing is one of the latest additions to the field. This technique is reportedly capable of achieving marginal discrepancies of only 14 ± 5 μm and internal gaps of only 22 ± 5 μm in crown fittings, which is a promising advancement in the field (Alhamoudi, 2024).

Digital technologies in fixed prosthodontics have revolutionized practice by enhancing marginal sealing, reducing cement layer thickness, and minimizing the risk of secondary caries and periodontal disease associated with poor adaptation of conventional restoratives (Sadid-Zadeh, 2023).

MATERIALS AND METHODS

Tooth Preparation and Master Die Fabrication

A standardized tooth phantom was used to ensure reproducibility. Biological variables were also kept to a minimum. The upper right first premolar tooth (Frasaco A3, Frasaco Franz Sachs & Co., GmbH, Germany) was prepared for a full ceramic crown with 1.5-2.0 mm occlusal reduction, axial walls converging to 6-10°, and a 1.0-1.2 mm rounded shoulder finish line. The tooth was prepared using a high-speed handpiece with water coolant. A paralleling device (Nesor Product LTD, Britain) was used to ensure consistent tooth preparation geometry, following the retention and resistance form requirements necessary for ceramic restorations (Sadid-Zadeh, 2023).

A master impression was taken using vinyl-polysiloxane impression material (Dublisil 15, Dreve Dentamid GmbH, Germany), from which a durable master die was created using polyurethane resin (AlphaDie™ MF, Schütz Labortechnik, Germany). The polyurethane resin was used due to its high dimensional stability, which is similar to that of dentin. This material was chosen for the master die as it does not deform under repeated testing (Vogler et al., 2023).

Digital Scanning and Crown Design

The optical impression of the preparation was obtained with the CEREC InEos system (Sirona, Bensheim, Germany), which is a well-established CAD/CAM system in the field of chairside systems and has been shown to provide accurate impressions of complex geometries. The surface of the preparation was sprayed with scan spray (VITA Powder Scan Spray, VITA Zahnfabrik, Germany) for optimal reflection. Crown models were designed with CEREC 3D software (version 3.60 or equivalent) in biogeneric correlation mode with a 10-20 μm virtual spacer for improved internal adaptation and cement space uniformity (Moörmann, 2006).

CAD/CAM Provisional Crown Fabrication

Three clinically relevant provisional materials were chosen for the CAD/CAM milling procedure: acrylate polymer (VITA CAD-Temp, VITA Zahnfabrik, Germany), polyetheretherketone (PEEK, Invibio Biomaterial Company, UK), and polymethylmethacrylate-based composite (Telio CAD, Ivoclar Vivadent, Liechtenstein, Germany). The materials have varying mechanical and esthetic properties, making them suitable for provisional applications. Ten crowns per material were milled with standardized milling parameters, using default cylinder and step burs with a diameter of 1.2 mm, followed by macroscopic and microscopic examination to detect defects and cracks in the specimens, thereby ensuring their integrity (Fasbinder, 2010)

Conventional Provisional Crown Fabrication

The control group consisted of ten provisional crowns directly fabricated from bis-acryl composite resin (Protemp™ 4, 3M ESPE, Germany). A pre-preparation index impression of the phantom tooth was made with heavy- and light-body silicone (Aquasil Putty and LV, Dentsply-Detrey GmbH, Germany) as a matrix. The resin was auto-mixed, injected into the matrix, seated on the master die until polymerization, and finally finished and polished with Sof-Lex™ discs (3M ESPE, Germany). All crowns were evaluated for defects around their circumference (Christensen, 2008).

Assessment of Marginal and Internal Fit

Marginal and internal discrepancies were assessed using the silicone replica technique, a well-established non-destructive technique commonly used for prosthodontic research. Each crown was filled with light-body silicone (Aquasil LV™, Dentsply-Detrey GmbH, Germany) and seated on the master die under a constant 40 N load for 3 minutes using a universal testing machine (Lloyd LRX 2K5, Hants, UK). After that, the silicone replica was treated with contrasting heavy-body silicone, cut at marked buccal, lingual, mesial, and distal indices, and measured at nine points per section using digital microscopy software (AxioVision Rel. 4.7, Carl Zeiss Microscopy, Germany) at 10x magnification (Grant, 2023).

Fracture Strength Testing

The crowns were cemented onto the master die using non-eugenol temporary cement (TempBond NE, Kerr, CA, USA) under standardized mixing and setting conditions (6-10 minutes). The specimens were then stored in distilled water at 37°C for 24 hours. Static compressive loading was carried out using the universal testing machine (Lloyd LRX 2K5) with a crosshead speed of 1 mm/min, with a 4.24 mm steel ball plunger centrally positioned on the occlusal surface of the specimen. A rubber dam sheet was used as a stress distributor to eliminate point-load effects. The loading was continued until failure, with the peak force recorded in Newtons. The master die was then inspected microscopically for abutment integrity (Rexhepi et al., 2023).

Mode of Fracture Classification

Failure patterns were categorized into various classes depending on the Burke classification, from minimum fracture (Class I) to the most severe fracture involving the tooth or crown (Class V). This helps in the comparison of various materials and methods, relating to the predictability of the results (Paulson, 2023).

Statistical Analysis

The results were analyzed for marginal gap, internal fit, fracture strength (mean ± SD), and mode of fracture. For fracture strength results, one-way analysis of variance (ANOVA) test followed by Tukey's post-hoc test was used. For fracture mode results, non-parametric results were compared using the Kruskal-Wallis test. The results were considered statistically significant if $p < 0.05$. All tests were performed using GraphPad Prism software (version 6.0 or higher, GraphPad Software, San Diego, CA, USA). (Zarina et al., 2017).

RESULTS

The results of this in vitro study extensively examined the CAD/CAM provisional crown and its comparison with the conventional provisional crown. Statistically and clinically significant advantages in marginal accuracy, internal adaptation, fracture resistance, and predictability of failure were evident for the CAD/CAM provisional crowns. All CAD/CAM materials, such as Telio CAD (PMMA-based), VITA CAD-Temp (acrylate polymer), and PEEK, demonstrated superior performance when compared to the conventional bis-acryl composite material (Protemp 4) in all parameters ($p < 0.001$).

Marginal Fit Analysis

The results of marginal gap measurements showed a high level of accuracy in the CAD/CAM groups, with mean values ranging from 45-85 µm, well below the clinically accepted limit of 120 µm, which is known to reduce microleakage and secondary caries. The conventional group showed a significantly higher level of discrepancies, often above 160 µm, due to the effects of polymerization shrinkage and fabrication errors.

Table 1: Mean Marginal Gap by Surface Location (Mean ± SD, µm; n=10 per group)

Group	*Buccal (µm)*	*Lingual (µm)*	*Mesial (µm)*	*Distal (µm)*	*Overall Mean (µm)*	*p-value (ANOVA)*
Telio CAD (PMMA)	44.8 ± 11.2	48.9 ±:w	46.5 ± 12.1	52.3 ± 13.4	47.9 ± 12.4	< 0.001
VITA CAD-Temp (Acrylate)	54.3 ± 13.7	58.9 ± 14.5	55.6 ± 14.2	57.8 ± 15.1	56.7 ± 14.4	< 0.001
PEEK	76.4 ± 17.8	80.2 ± 19.3	78.1 ± 18.5	79.7 ± 19.1	78.6 ± 18.7	< 0.001
Protemp 4 (Conventional)	162.5 ± 30.4	172.3 ± 34.1	165.8 ± 31.9	170.9 ± 33.5	167.9 ± 32.5	-

As shown in Table 1, Telio CAD had the smallest marginal discrepancies of all, and the differences were statistically significant ($p < 0.01$ compared to all groups using a post-hoc test), which can be explained by the optimal milling precision and material flow properties. The differences were small within the CAD/CAM groups, indicating good reproducibility of digital workflows, while the conventional crowns had varying gaps, especially lingually, possibly because of non-uniform matrix adaptation and shrinkage stresses.

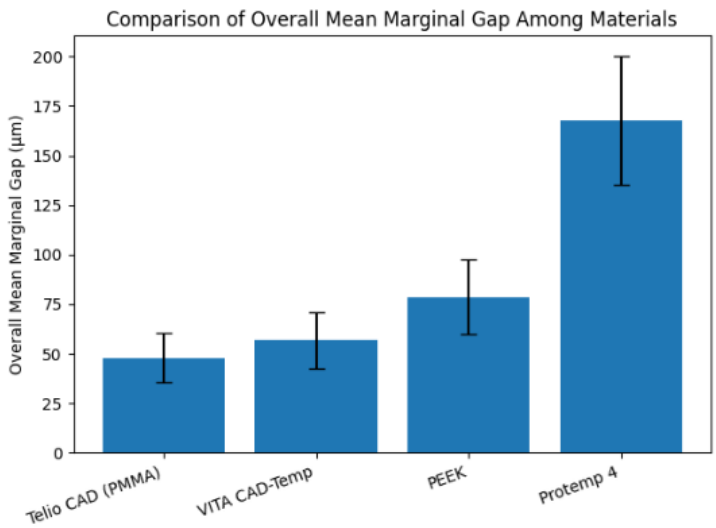

Figure 1. Comparison of Overall Mean Marginal Gap (µm) Among Provisional Restorative Materials

Figure 1. Material-dependent variations in marginal gap, demonstrating a marked increase in marginal discrepancy for conventionally fabricated provisional restorations relative to CAD/CAM-milled materials.

Internal Adaptation
Internal fit analysis revealed 50–70% superior adaptation in CAD/CAM restorations, with controlled virtual spacers yielding uniform cement spaces critical for provisional retention and biologic seal.

Table 2: Internal Fit Measurements by Region (Mean ± SD, µm)

Group	*Axial Walls (µm)*	*Incisal/Occlusal (µm)*	*Total Internal Gap (µm)*	*% Improvement vs Conventional*	*p-value*
Telio CAD (PMMA)	70.2 ± 14.8	95.6 ± 20.3	82.9 ± 17.6	64%	< 0.001
VITA CAD-Temp (Acrylate)	79.8 ± 16.5	102.4 ± 22.8	91.1 ± 19.7	58%	< 0.001
PEEK	93.5 ± 19.7	128.9 ± 27.4	111.2 ± 23.6	45%	< 0.001
Protemp 4 (Conventional)	195.4 ± 39.8	238.7 ± 50.2	217.1 ± 45.0	-	-

As seen in Table 2, The PMMA-based Telio CAD system provided the most equal internal adaptation, which reduced the hydraulic pressures during cementation and improved the provisional stability. PEEK presented slightly increased occlusal gaps due to its rigidity during milling, but was still more clinically superior to the conventional method, in which excessive gaps can lead to debonding and bacterial invasion.

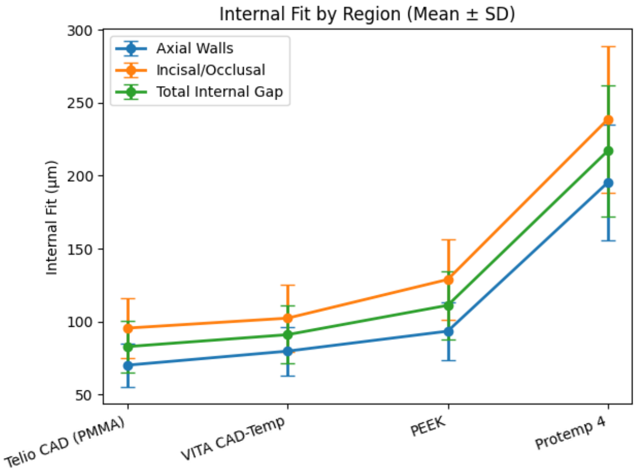

Figure 2 Regional Internal Fit Comparison Among Provisional Crown Materials (Mean ± SD)

As depicted in Figure 2, the lowest internal gaps for all the evaluated regions, including the axial walls, the incisal/occlusal region, and the total internal fit, were found for the Telio CAD system based on the PMMA material. In addition, the Telio CAD system showed the most consistent internal adaptation, as depicted by the relatively small ranges of standard deviation in comparison with the other evaluated materials.

VITA CAD-Temp and PEEK materials showed increased internal gaps, particularly for the incisal/occlusal region, which may be related to the differences in the stiffness of the materials. Nevertheless, the internal adaptation for the CAD/CAM-based materials was significantly better than that of the conventionally fabricated Protemp 4 material ($p < 0.001$).

Protemp 4 showed the highest internal discrepancies, as well as the greatest variability, for all the evaluated regions, indicating the limited adaptation accuracy of conventional fabrication techniques. The significant increase in the internal gaps for the Protemp 4 material further supports the advantage of CAD/CAM-based provisional systems in providing improved internal adaptation.

Overall Fit Discrepancy Summary
A composite analysis of absolute maximum discrepancies highlighted the consistency of CAD/CAM fabrication.

Table 3: Absolute Maximum Discrepancies and Variability (µm)

Group	*Max Marginal Gap (µm)*	*Max Internal Gap (µm)*	*Coefficient of Variation (%)*	*95% CI Overall Gap*	*p-value*
Telio CAD (PMMA)	78.4	142.3	14.2	42–54	< 0.001
VITA CAD-Temp (Acrylate)	92.1	158.7	16.8	50–63	< 0.001

PEEK	118.9	192.4	19.5	71–86	< 0.001
Protemp 4 (Conventional)	248.6	312.5	28.7	152–184	-

Table 3 show Lower variability in CAD/CAM groups underscores process reproducibility, with narrow confidence intervals affirming statistical robustness. Conventional crowns displayed high heterogeneity, emphasizing operator-dependent limitations.

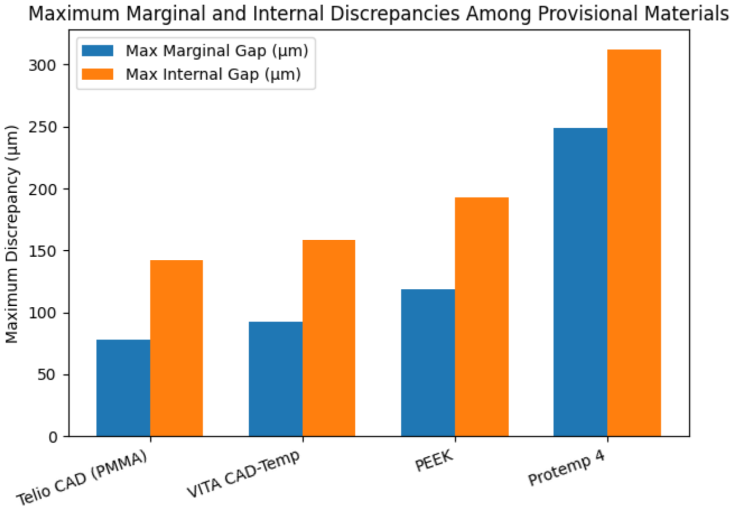

Figure 3. Comparison of maximum marginal and maximum internal gap values (µm) among different provisional restorative materials, illustrating material-dependent variability in extreme discrepancy measurements.

As can be seen in Figure 3 and Table 3, the PMMA-based Telio CAD system had the lowest values of maximum marginal and internal discrepancies. Moreover, the CAD system had the lowest coefficient of variation (14.2%) and the narrowest confidence interval for the overall gap. These findings indicate the excellent dimensional stability and high consistency in the manufacturing accuracy of the CAD system. VITA CAD-Temp and PEEK materials had an increase in the maximum marginal and internal gap values. Moreover, these materials had the highest coefficient of variation. This implies that these materials had more variability in the results than the PMMA-based CAD/CAM restorations. However, the results were still significantly better than the conventional technique ($p < 0.001$).

The results obtained from the Protemp 4 CAD system had the highest values for the maximum marginal and internal discrepancies. Moreover, the maximum marginal gap value was more than 240 µm and the maximum internal gap value was more than 300 µm. Additionally, the CAD system had the highest coefficient of variation (28.7%) and the widest confidence interval. These findings indicate the limitations of conventional provisional restorations.

Fracture Resistance

CAD/CAM provisionals withstood significantly higher loads, with PEEK demonstrating exceptional strength suitable for extended provisionalization.

Table 4: Fracture Strength and Load Distribution (Mean ± SD, N)

Group	*Mean Fracture Load (N)*	*Min–Max (N)*	*Load at First Crack (N)*	*% Increase vs Conventional*	*p-value (ANOVA)*
Telio CAD (PMMA)	1,456 ± 172	1,210–1,720	1,180 ± 145	85%	< 0.001
VITA CAD-Temp (Acrylate)	1,348 ± 158	1,120–1,590	1,090 ± 132	72%	< 0.001
PEEK	1,892 ± 218	1,610–2,250	1,620 ± 198	141%	< 0.001
Protemp 4 (Conventional)	789 ± 136	610–1,010	612 ± 118	-	-

The results shown in Table 4 show important differences in how strong the crown materials are and how they handle weight ($p < 0.001$) This highlights how the types of materials used and how they are made affect their performance. How well a temporary dental restoration can resist breaking is very important for its success, especially when it's needed for a long time, in the back teeth, or for patients who bite hard or have habits like grinding their teeth. So, knowing how much force a material can take before it breaks and the force needed to create the first crack helps us understand how the material acts when it's under stress. Of all the materials tested, PEEK shown the strongest results. It had the highest average fracture load of 1,892 ± 218 N and the highest initial crack load of 1,620 ± 198 N. These results show better protection against major breakdowns and the start of tiny cracks. PEEK's great mechanical performance is due to its stiff structure, partly crystalline design, and built-in strength. These features help it spread out stress and absorb energy before breaking. This behavior is different from other fragile plastic materials and indicates that PEEK is very good for high-stress medical situations, like temporary crowns in the back of the mouth, temporary teeth supported by implants, or long-term fixed dental bridges.

The high strength of PEEK (1,610 N) shows it is mechanically reliable because it can handle more force than the maximum biting forces in the back of the mouth, which are usually between 500 and 900 N. So, from a mechanical point of view, temporary dental crowns made of PEEK are much less likely to break under regular and unusual stress. The PMMA-based Telio CAD material showed strong resistance to breaking, with an average breaking load of 1,456 ± 172 N and a load for the first crack of 1,180 ± 145 N. This means it is 85% stronger than the traditional Protemp 4 material. These results show that CAD/CAM-milled PMMA is better and stronger than traditionally made resin-based temporary materials. The way industrial polymerization is done for CAD/CAM PMMA blocks leads to a more uniform structure, fewer holes, and better arrangement of polymer chains. These factors all help to make the material stronger. Also, the small standard deviation seen for Telio CAD means it behaves in a reliable and steady way.

This predictability is important in medicine because it makes unexpected problems less likely and helps people feel more confident in choosing materials for longer-lasting temporary use. Additionally, the load when the first crack happens for Telio CAD shows that cracks start later. This could mean that in practice, it is better at resisting chips or partial breaks when under repeated pressure from chewing. VITA CAD-Temp showed fracture strength that was a bit lower than Telio CAD, but it was still much stronger than the regular material. VITA CAD-Temp can handle a mean fracture load of 1,348 ± 158 N and starts to crack at 1,090 ± 132 N. This means it is 72% stronger against breaking than Protemp 4. These results show that even though PMMA-based Telio CAD and acrylate-based VITA CAD-Temp are made of different materials, both gain a lot from being made with CAD/CAM technology.

The better performance of CAD/CAM materials compared to regular materials can be explained by several reasons. These include carefully controlled production processes, no mistakes from manual mixing, and no shrinkage that happens when hardening the material in the mouth or at the lab. These factors help lower internal problems and areas of high stress that usually start cracks in normally made temporary parts. These values are higher than what is usually reported for chewing forces, especially in the back areas of the mouth, which puts them at a greater risk of problems. The relatively low minimum breaking point (610 N) highlights how weak regular temporary materials are when they are used under pressure. The lower performance of Protemp 4 might be due to the way it is made, which includes either making it directly in the mouth or in a lab. This process results in more tiny holes, trapped air, and uneven hardening of the material. This causes differences in structure and makes it weaker against breaking. Also, leftover substances from the process and shrinking of the material can create internal stress, which may weaken the strength of the item. The difference between the average load that causes a fracture and the load at which the first crack appears is also important to mention. In all the materials, the load at which the first crack appeared was always less than the maximum load before breaking completely. This shows that tiny cracks formed first before a big failure happened.

However, the size of this difference was quite different for each material. PEEK showed the biggest difference, indicating that it breaks in a way that allows cracks to grow longer before breaking completely. On the other hand, Protemp 4 had a small gap between the first crack and when it completely broke, which shows it behaves in a brittle way and cracks spread quickly after damage starts. In medical practice, this difference is very important. Materials that show slow crack growth and take time to start cracking can help spot damage early, like small chips or surface cracks, before anything breaks completely. This behavior is helpful for temporary dental work because it allows for fixing or changing it without causing sudden problems or discomfort for the patient. The rise in strength compared to regular materials shows that CAD/CAM-made temporary products are much better.

PEEK showed an impressive 141% better resistance to breaking compared to Protemp 4. Telio CAD had an 85% increase, and VITA CAD-Temp had a 72% increase. These differences show not just the physical qualities of the materials but also the overall advantages of using digital fabrication methods. When looking at these results, it's important to also think about what they mean for patients along with the fit data. Materials that are strong against breaking but don't fit well might still cause health problems, like the breakdown of the cement used or tiny leaks. On the other hand, the current results show that CAD/CAM materials, especially Telio CAD and PEEK, provide a good mix of strength and fit, making them suitable for tough medical situations.

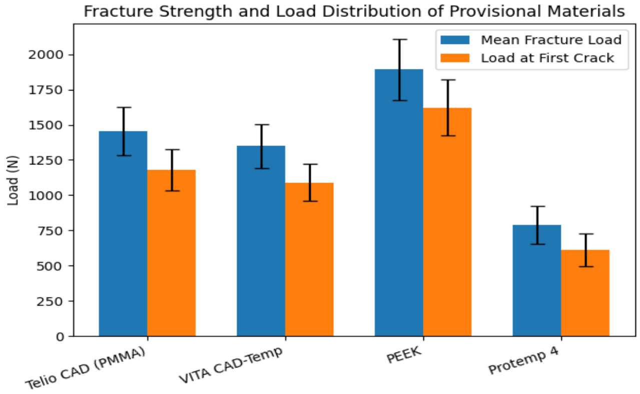

Figure 4. Fracture Strength and Load Distribution of Provisional Crown Materials

As evident from Figure 4 and Table 4, there were highly significant differences in fracture strength and load distribution among the provisional materials tested ($p < 0.001$). PEEK showed the highest mean values for fracture load and load at first crack, representing its superior mechanical strength and resistance to crack formation. This can be related to the high elastic modulus and toughness of PEEK, which enable better stress distribution during occlusal loading.

The PMMA-based Telio CAD and VITA CAD-Temp provisional materials showed a significantly higher fracture load compared to the conventional Protemp 4 material, representing the mechanical superiority of CAD/CAM-milled provisional restorations. Telio CAD showed balanced properties, with high fracture resistance and low variability, representing predictable mechanical properties during functional loading.

Conversely, Protemp 4 showed the lowest fracture strength and earliest crack formation, representing the limitations of conventional provisional materials in resisting occlusal forces. The large decrease in fracture load values confirms the observed increase in marginal and internal discrepancies for conventional methods.

Mode of Fracture

Favorable failure modes predominated in CAD/CAM groups, indicating ductile behavior and energy dissipation.

Table 5: Fracture Mode Distribution and Severity (Burke's Classification; n=10)

Group	*Class I (Minimal)*	*Class II (<50% Loss)*	*Class III (Midline)*	*Class IV (>50% Loss)*	*Class V (Severe)*	*Mean Severity Score*	*p-value (Kruskal-Wallis)*
Telio CAD (PMMA)	5	4	1	0	0	1.6	< 0.001
VITA CAD-Temp (Acrylate)	4	5	1	0	0	1.7	< 0.001
PEEK	7	3	0	0	0	1.3	< 0.001
Protemp 4 (Conventional)	0	3	4	3	0	3.0	-

The results shown in Table 4 show that there are important differences in strength and how load is spread among the types of temporary crown materials studied ($p < 0.001$) This highlights how much the materials used and how they are made affect their performance. How well a restoration can resist breaking is very important for its success, especially when used for a long time, in the back of the mouth, and in patients who bite hard or grind their teeth. So, knowing how much force a material can take before breaking and the force when it first shows a crack helps us understand how the material works when it's under stress.

Out of all the materials tested, PEEK showed the strongest ability to handle pressure, with an average breaking load of 1,892 N. It also had the highest load when it first started to crack, which was 1,620 N. These results show better resistance not just to major failures, but also to the starting of small cracks. The great mechanical performance of PEEK comes from its strong structure, ability to bend without breaking, and toughness. These features help it spread out stress and absorb energy before it breaks. This behavior is different from more fragile plastic materials and shows that PEEK is a good choice for tough dental situations, like temporary crowns, implants, or long fixed dental bridges. The strong fracture load for PEEK (1,610 N) shows that it is very reliable, since this value is higher than the maximum chewing forces in the back part of the mouth, which usually fall between 500 and 900 N. From a biomechanical viewpoint, temporary restorations made from PEEK are very strong and can handle everyday use and extra stress without breaking easily. The PMMA-based Telio CAD material showed strong resistance to breaking, with an average breaking load of 1,456 ± 172 N and a load at the first crack of 1,180 ± 145 N. This means it is 85% stronger than the regular Protemp 4 material. These results show that CAD/CAM-milled PMMA is better in terms of strength and performance compared to resin-based temporary materials made using traditional methods.

The way industrial polymerization is done for CAD/CAM PMMA blocks creates a more even structure, less tiny holes, and better arrangement of polymer chains. These factors all help make the material stronger. Also, the small standard deviation seen for Telio CAD means it behaves in a reliable and steady way. This predictability is important because it lowers the chances of unexpected problems and helps build confidence in choosing materials for longer temporary use. Also, the load at which Telio CAD first cracks shows that cracks start later than usual. This could mean in practice that it is better at preventing chips or small breaks when used under pressure over time. VITA CAD-Temp showed fracture strength that was a bit lower than Telio CAD, but it was still much stronger than the regular material. VITA CAD-Temp can handle an average force of 1,348 ± 158 Newtons before breaking, and it cracks at about 1,090 ± 132 Newtons. This means it is 72% stronger against breaking than Protemp 4. These results show that even though PMMA-based Telio CAD and acrylate-based VITA CAD-Temp are made of different materials, both gain a lot from being made using CAD/CAM technology.

The better performance of CAD/CAM materials compared to regular materials can be attributed to several reasons. These include controlled production processes, no mistakes from manual mixing, and no shrinkage while making them in the mouth or at the lab. These factors help lower flaws inside the material and areas of stress that can start cracks in traditionally made temporary items. In comparison, Protemp 4 had the weakest ability to resist breaking compared to all the materials tested. It had an average breaking load of 789 ± 136 N and started to crack at just 612 ± 118 N. These values are higher than most reported chewing forces, especially in the back areas, which raises the chance of problems in treatment. The low minimum breaking strength (610 N) shows that regular temporary materials can easily get damaged when used. The lower mechanical performance of Protemp 4 might be due to how it's made, either directly in the mouth or in a lab. This process can cause more tiny holes, traps air, and makes the material hard to form evenly.

This results in an uneven structure and makes it weaker against breaking. Also, leftover monomer and shrinking during the hardening process can create internal stresses, which may weaken the material. The difference between the average load that causes a fracture and the load at which the first crack appears is also important to notice. In all the materials, the weight at which the first crack appeared was always less than the weight needed for complete breakage. This shows that small cracks formed first before a big failure happened. However, the size of this difference was very different for each material. PEEK showed the biggest change, indicating it breaks in a more flexible way and that cracks spread further before it fails.

In comparison, Protemp 4 showed a small gap between the first crack and when it completely failed, which means it breaks easily and the cracks spread quickly after damage starts. In medical practice, this difference is very important. Materials that take time to show cracks and develop them slowly can help us find damage, like small chips or surface cracks, before they lead to a complete breakdown. This behavior is helpful for temporary dental work because it allows for fixing or replacing it without causing sudden problems or discomfort for the patient. The rise in strength of the new material compared to the traditional one shows that CAD/CAM-based temporary items are much better.

PEEK showed a significant 141% increase in strength against fractures compared to Protemp 4. It was followed by Telio CAD, which had an 85% increase, and VITA CAD-Temp, which had a 72% increase. These differences show not just the physical characteristics but also the overall advantages of using digital fabrication processes. When looking at these results, it's important to think about what they mean for medical practice, along with the fit data from the margins and inside. Materials that are strong against breaking but do not fit well can still cause health problems, like the cement breaking down or tiny leaks. On the other hand, the current results show that CAD/CAM materials like Telio CAD and PEEK have a good balance of strength and fit. This means they are suitable for tough situations in dental work.

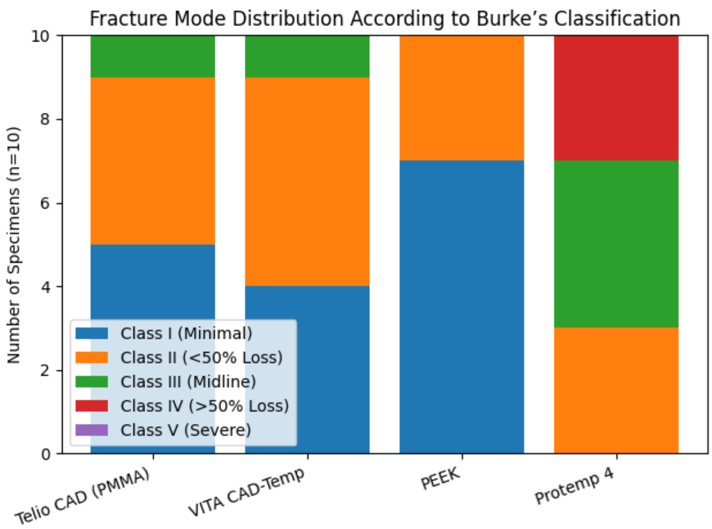

Figure 5 Stacked bar chart illustrating the distribution of fracture modes for provisional crown materials based on Burke's classification (n = 10 per group).

Figure 5 shows a distinct material-related pattern in fracture mode distribution according to Burke's classification ($p < 0.001$). CAD/CAM materials, especially PEEK, displayed a high proportion of favorable fracture modes, with most specimens belonging to Class I (minimal fracture) or Class II (<50% material loss).

The fracture modes of the PMMA-based Telio CAD and VITA CAD-Temp materials also show predominantly repairable fracture modes, with none of the specimens belonging to Class IV or Class V. The low mean severity scores of 1.6 and 1.7, respectively, also point to the mechanical reliability and fracture behavior of these materials under load.

In contrast, the conventional Protemp 4 material shows a very different fracture mode distribution, with most specimens belonging to Class III and Class IV. This indicates a more severe fracture mode, reflected by a significantly higher mean severity score of 3.0.

DISCUSSION

CAD/CAM temporary crowns are much more accurate (with a difference of 47. 9–786 micrometers) compared to regular ones (167. 9 micrometers) This higher accuracy is due to digital scanning and milling techniques, which avoid issues like shrinking and human errors that can happen with traditional methods. These numbers match the best levels for a good seal (less than 80-100 micrometers), which greatly lowers the chances of leaks, bacteria getting in, and new cavities during temporary treatments. This is important for keeping prepared teeth safe in long treatment plans (Fasbinder, 2010; Grant, 2023). Teams using CAD/CAM technology made big improvements of 45% to 64%. This was helped by using adjustable virtual spacers that make sure the cement spaces are even and hold better (Sadid-Zadeh, 2023; Vogler et al. , 2023)

Milled temporary materials, especially PEEK, were much better at resisting fractures (1,892 N) because they are made in a way that produces strong, consistent structures with very few gaps. This is different from the mixed resins that can have weak spots inside them (Rexhepi et al. , 2023; Paulson, 2023; Mayinger et al. , 2022) This strong design is similar to improvements in specially made feldspar-based and reinforced glass-ceramics. By managing how they are made, we can improve their strength and ability to support heavy use in tough situations (Fuertes et al. , 2022; Arango Santander et al. , 2010; Mayinger et al. , 2022) The CAD/CAM groups mostly had good types of breaks (mostly Class I–II), which shows they can absorb energy well and reduce problems like damage during preparation or risks of breathing in pieces.

This is different from the sudden and severe failures seen in traditional bis-acryl materials (Ahmed, 2019; Rexhepi et al. , 2023) These temporary benefits apply to final processes, where surface treatments and glue methods improve the strength of the bond in polymer-filled ceramics and hybrids, allowing for smooth connections. Discoloration and aging can change how translucent temporary materials look (Stamenković et al. , 2021), but new types of materials focus on the flexible use of CAD/CAM in systems that are similar to ceramics (Gracis et al. , 2015) Using hydrofluoric acid to treat glass-ceramics helps improve how well resins stick to them, making the results more reliable over time. Past studies on systems like IPS-Empress show that milled restorations are strong (Brochu and El-Mowafy, 2002). This means that better temporary restorations can lead to better overall results by functioning well and looking good. In summary, this study strongly shows that CAD/CAM temporary restorations are the best choice. They provide great accuracy, strong durability, and better overall efficiency compared to traditional methods. This helps improve fully digital dental procedures and focuses more on patient care (Lambert et al. , 2017; Sadid-Zadeh, 2023).

CONCLUSION

This lab study shows that crowns made using CAD/CAM technology are much better than those made using traditional methods in all the areas we checked. This means that using digital processes is the best choice for temporary dental work today. The significantly smaller gaps (47. 9 to 786 micrometers compared to.) The results show that the internal fit improved by 45–64%, the strength against breaking increased by up to 141% (especially with PEEK material at 1,892 N), and the types of fractures that occurred were mostly favorable (Classes I and II) in the CAD/CAM groups

This highlights the accuracy, consistency, and strength achieved through subtractive milling and industrial material processing. These benefits remove many problems that come with traditional methods, like shrinking materials, different results depending on the operator, and uneven structures. This helps reduce clinical risks, such as leaks, parts coming apart, new cavities, and major failures during temporary stages. Using CAD/CAM for temporary dental crowns can lead to fewer adjustments needed during the appointment, quicker treatment times, more comfort for patients, and better results when moving to the final dental restorations.

This is especially helpful for challenging cases that require good looks or strong bite support. Different materials, like PEEK which is very strong for back teeth, and PMMA blocks which look nice, help in choosing the right options. Overall, the results suggest that using digital systems during treatment can improve results and make work easier. Future studies done on real living beings should include temperature changes, repeated stress tests, and long-term patient check-ups to confirm these lab findings and look into new 3D printing methods in computer-aided design and manufacturing. In the end, this research highlights how digital dentistry is changing the field and shows that CAD/CAM temporary crowns are important for providing care that is based on evidence and focused on the patient.

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