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Comparison of Fractural Strength of Acrylic Resin Crowns Reinforced with Titanium Oxide, Graphene Oxide and Zirconia Crown – an in Vitro Study

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PMMA, Graphene Oxide, Titanium Oxide, Zirconia And Fractural Strength

ABSTRACT:

Aim: Comparison of fractural strength of acrylic resin crowns reinforced with titanium oxide, graphene oxide and zirconia crown.

Setting and Study Design: In-vitro comparative study.

Materials and Method: A stainless-steel metal die was fabricated to mimic the molar abutment and the die was used to fabricate the 45 testing samples. These test samples were divided into three groups. Group A was consisted of 15 zirconia crowns, group B was consisted of 15 PMMA reinforced with titanium oxide crowns and group C had 15 PMMA reinforced with Graphene oxide crowns. A universal testing machine (round headed; 10mm diameter) at a speed of 0.5mm/min was used to compare and evaluate the fractural strength of the specimens.

Statistical Analysis: The results were analysed using SPSS software Version 25.0 (SPSS Inc., Chicago, IL, USA). One way ANOVA was used to compare the mean scores. For all statistical purposes, significant difference in bond strength was noted.

Result: The results revealed that PMMA reinforced with graphene oxide exhibited the highest mean fractural strength (2147.8 N), outperforming PMMA reinforced with titanium oxide(1429.0 N) and zirconia(1156.7 N). One way ANOVA test for fractural strength showed a significant difference among the specimens.

Conclusion: PMMA reinforced with graphene oxide showed significant higher fractural resistance than other two materials. These findings suggest that PMMA reinforced graphene oxide, enhances the mechanical properties of PMMA. This research holds a promise for transforming dental prosthetics by presenting a new material that is comparable to zirconia and making it a material for long-term restorations in prosthodontics.

Introduction

According to the Glossary of Prosthodontic Terms (GPT), a provisional restoration is a "fixed or removable dental prosthesis that is designed to improve aesthetics, stability and/or function for a specific period of time, after which it should be replaced by a permanent dental prosthesis.Interim restorations are primarily used to manage soft tissue, safeguard the

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dentin-pulp complex, stabilise the tooth within the arch, and evaluate the masticatory function, shape, and aesthetics of the planned restoration.[1, 2, 3] When choosing a material for temporary restorations, it is important to consider its physical, mechanical, and handling characteristics to make sure it meets the needs of each unique clinical scenario.[4-6] The goal of interim restorations is to keep the teeth in their proper positions while adhering to cosmetic standards, marginal accuracy, and wear and structural resistance. In order to anticipate potential future restorations, provisionalization is a crucial stage while the periodontal tissues heal and the abutments regain their health. Since some materials may release toxic components, other necessary criteria includes biocompatibility with the oral environment and integration with both hard and soft tissues.[7] When creating temporary fixed partial dentures (FPDs), materials such as polymethyl methacrylate (PMMA), polyethyl methacrylate, bis-acryl composite (BAC), and epimine resin are frequently utilised. These materials need to be robust enough to endure masticatory stresses, especially for patients with parafunctional habits or long span FDPs. [GEERTS]For a very long time, prosthodontists have been using acrylic resins, and in particular Polymethyl Methacrylate (PMMA), as a temporary restorative material. Low elastic modulus which reduces antagonist tooth wear[8], good aesthetic outcomes, ease of repairability, low cost and a somewhat quick manufacturing process are only a few of their advantageous qualities. Their main shortcomings are their limited resistance to deterioration, wear and tear and volume contraction upon polymerisation [9]. Furthermore, the microbial adherence to PMMA and their susceptibility to fatigue failure [10] pose a serious drawback to their long-term use. Various techniques have been developed to improve the physical characteristics of interim FPDs. Using metal and fibre reinforcements have produced positive outcomes. The amount and orientation of the fibres, as well as their position, impregnation, and adherence to the polymer matrix, all affect the ultimate strength of the reinforced resin. [GEERTS]Safe-to-use nanofillers are frequently used to reinforce dental materials in order to achieve good mechanical strength in the oral environment. Graphene oxide, ZrO_2, TiO_2, glass fibres, and hydroxy apatite are examples of nanoparticles that are frequently utilised. [11] The main component of graphene oxide is carbon atoms organised in a unique two-dimensional honeycomb structure. Graphene oxide's remarkable characteristics and distinct look are a result of the covalent bonding of carbon atoms in a flat sheet.[12] Graphene oxide (GO) and reduced graphene oxide (rGO), two of its derivatives, can be functionalised and mixed with polymers to create composites with specific characteristics. Graphene is a good material for dental restorative because its tensile properties are similar to those of bone, enamel, and dentine [13]. It has been demonstrated that adding graphene oxide to acrylic resin can improve its mechanical characteristics, decrease polymerisation contraction, and improve its antibacterial adherence, making it a viable choice for dental applications [14]. Graphene has good compatibility and the previously described qualities, which make it useful in dentistry. Due to its exceptional stability, catalytic function, widespread availability, white colour, efficiency, and affordability, TiO_2 nanoparticles have also recently attracted interest. TiO_2 is a thermally stable substance. In addition to being resistant to chemical attacks, TiO_2 nanoparticles are very biocompatible and have a huge surface area because of their nanosize. [11] TiO_2 nanoparticles also have a high refractive index, are corrosion-resistant, non-toxic, chemically inert, and have broad-spectrum antibacterial and photocatalytic activity. [15,16]TiO_2 nanoparticles have been utilised in dentistry to enhance dental implants' osseointegration, the material's antibacterial capacity, endodontically treated teeth's resistance to fracture, and adhesives' ability to bind to human teeth. [11] The form, hardness, elasticity, and hydrophilicity of PMMA-based temporary crown materials are altered by inorganic nanofillers. TiO_2 and graphene oxide are not commonly used for short-term repairs. According to numerous studies, fractures are the most frequent cause of temporary repair failure, which results in pain, suffering, and monetary losses.For these reasons, when choosing a material for certain applications, fracture resistance is important and should be considered. [17] Because of its strength and beauty, zirconia is frequently used in dentistry. Its exceptional mechanical qualities, high flexural strength, fracture toughness, and excellent biocompatibility reduce tissue irritation and allergic reactions . As an alternative to

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titanium or alumina, zirconium oxide (ZrO2) was offered as a material for hip replacement prostheses. ZrO2 has excellent mechanical and cosmetic qualities. In dentistry, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) endodontic posts, dental implants, and dental prostheses are frequently made from Zr-based materials. Zirconia-based fillers have been proved to improve the composites' toughness and tensile bond strength in a prior study.[18]Naturally, three crystallographic structures were identified for zirconia: the cubic (c-), tetragonal (t-), and monoclinic (m-) phases. Elevating the temperature to 1170°C causes the m-phase to change into the t-phase, which is relatively stable at room temperature. When zirconia reaches 2370°C, it eventually has the potential of transition to the c-phase. Addition of 3% yttrium to zirconia can suppress the t-m phase transformation and stabilize the generated t-phase. Furthermore, zirconia-based prostheses are now more durable and long-lasting due to improvements in bonding methods and adhesive solutions that have greatly strengthened the link between zirconia restorations and dental substrates [19]. The goal of the current study is to compare the fractural strength of PMMA crowns made of zirconia, graphene oxide, and titanium oxide. Our goal is to determine whether graphene oxide can replace zirconia in permanent dental restorations. This research offers a unique material that combines the cost-effectiveness and adaptability of graphene with the aesthetic appeal of zirconia, which holds great promise for revolutionising dental prosthesis.

Materials and Methods

The research was divided into the subsequent stages: -

1. Fabrication of a metal die

2. Fabrication of working die

3. Fabrication of 45 test samples. These test samples were divided into three groups.

a) Group A: 15 zirconia crowns.

b) Group B: 15 PMMA reinforced with titanium oxide crowns.

4. Group C: 15 PMMA reinforced with Graphene oxide crowns.

5. Testing of the different group specimens for fractural strength under universal testing machine.

6. Statistical analysis and result.

Metal die fabrication

A 1.2 mm-wide chamfer edge was incorporated into a cylindrical stainless-steel die designed to resemble a molar abutment. It had a total convergence angle of 12 degrees, with an axial height of 5.5 mm and a tapering angle of 6 degrees. The cervical and occlusal line angles of the abutment were rounded. 6.0 mm and 7.0 mm in diameter, respectively (figure 1a). This abutment, which had been set above a cylindrical metal base (figure 1b), functioned as the die for the creation of the metal working model.

Fabrication of working die:

A vinyl poly-siloxane (flexseed, GC dental products crops, Japan) putty impression material was mixed, and it was placed on the metal die. After setting, the impression was removed and checked for any damage to the contour. The impression was poured with type IV dental stone (KalrockKalabhai Larson Indian Pvt. Ltd., India) in a 100g/20ml ratio according to the manufacturer's instructions. This working die was utilised for the fabrication of all the three test groups.

Fabrication of samples

a) Fabrication of Group A (zirconia crowns)

The working die was sprayed (Easy scan; Alpha dent) with scan spray and scanned using a digital scanner 3Shape D700 (TS) (3Shape, Copenhagen, Denmark), and it was used to design the zirconia crowns (Amann Girrbach GmbH, Pforzheim, Germany) with computer-assisted design CAD (Ceramill®EXO 4.0 CAD) software. The digitally designed crowns for this group were confirmed to have an identical anatomy, contour, and emergence profile using computerized control milling. The digital files were transferred toCAM (Arum 5X-450) to milled the zirconia blocks [figure 2 (a)].

b) Fabrications of Group B (PMMA reinforced with titanium di oxide) crowns

A wax pattern was created by molding inlay wax (Pyrax Roorkee, India) onto the working die to shape the temporary crowns with proper contouring and anatomy.

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The die with the wax pattern was flasked, counter-flasked, and de-waxed. PMMA resin (DPI heat cure, 792, Mumbai Maharashtra, India) mixed with 5% Wt titanium dioxide (TECHINSTRO, India)(2:1 ratio) along with monomer according to manufacturer instructions and allowed to reach the dough stage. After kneading and packing, trial closure was performed to remove excess material. The flask was clamped and maintained under 500gm pressure for 20 minutes.Theseflasks were heat cured at 74ºC for 2hrs and increasing the temperature of water bath to 100º C and processing for 1 hr, which were then bench cured for 30 minutes.After cooling at room temperature, specimens were de-flasked, finished, and polished (400 and 600 grit silicon carbide paper) [figure 2(b)]

c) Fabrications of Group C (PMMA reinforced with graphene oxide) crowns

The working die was sprayed (Easy scan; Alpha dent) and scanned, provisional restorations from Prefabricated blocks of PMMA reinforced with graphene oxide (G-CAM, Graphenano Dental, Valencia, Spain) were then designed by the CAD software(Ceramill®EXO 4.0 CAD)and blocks were milled by a CAM (Arum 5X-450) [figure 2(c)]

1) **Fracture strength test evaluation**

For fracture testing, the prepared stainless-steel tooth model was put in a universal testing device (INSTRON 3382 series running Bluehill software). This model was used to hold the specimens. Without cementation, the crowns were securely placed on a metal die. In the centre of the occlusal plane between the buccal and palatal cusps of the specimen, the piston was activated, and the compressive load was applied vertically from the occlusal surface at a 90-degree angle with a crosshead (round ended; 10 mm diameter) speed of 0.5 mm/min until the specimen fractured. For every crown [figure 4(a), (b), and (c)], the compressive load (N) at the point of failure and the durable period till each crown reached fracture strength were recorded.

Statistical analysis

After calculating the compressive force at the site of failure, the time until fracture for each group of crowns, and their mean (M) and standard deviation (SD), Data were entered into a Microsoft Excel spreadsheet, and SPSS software, version 25.0 (SPSS Inc., Chicago, IL, USA), was used to evaluate the descriptive data. The mean scores were compared using a one-way ANOVA. A significance threshold of ≤ 0.05 was applied to all statistical analyses.

Results

In this study, the ASTM method was used to examine the fracture strengths of zirconia, PMMA reinforced with graphene oxide, and PMMA with titanium oxide. A 5mm diameter spherical head mounted in a computer-controlled universal testing machine at a crosshead speed of 0.5 mm/min was used to subject all of the samples in Group A (zirconia), Group B (PMMA reinforced with titanium di oxide), and Group C (PMMA reinforced with graphene oxide) to compressive axial loading. The force at which the material fractured was recorded. According to the findings, the PMMA including graphene oxide had mean fracture strength of 2147.8 N, which was more than the PMMA containing zirconia and titanium oxide. Zirconia had a fracture strength of 1156.7 N, whereas PMMA with titanium oxide had the second-highest fracture strength of 1429.0 N. The difference between the three groups was statistically extremely significant (p-0.000). [Figure 4, Table 1]

Tables 1: Comparison of mean fracture strength of Zirconia, PMMA with titaniumoxide and PMMA reinforced graphene oxide (n=45) (SD- Standard Deviation, n-number of samples, *HS- Statistically highly significant.

Groups	n	Fracture strength (N)	95% Confidence Interval of the Difference		Minimum	Maximum	F-value	p-value
		Mean± SD	Lower	Upper				
Group A	**15**	**1156.7±89.54**	1108.08	1205.4	1075.4	1287.6		

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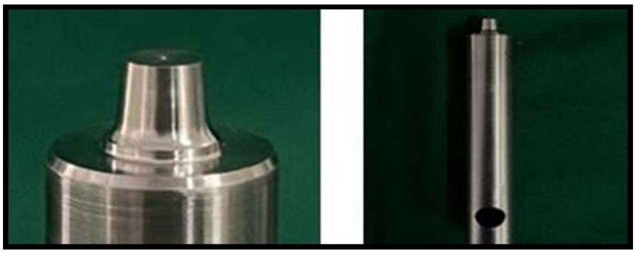
(Zirconia)								
Group B (PMMA with titanium-di-oxide)	**15**	**1429.0±197.8**	1321.4	1536.5	1207.9	1756.7	227. 78	**0.000* (HS)**
Group C (G-CAM)	**15**	**2147.8±79.4**	2103.8	2191.8	2047.9	2266.8		



Figures 1: A- metal die B- metal die with cylindrical base

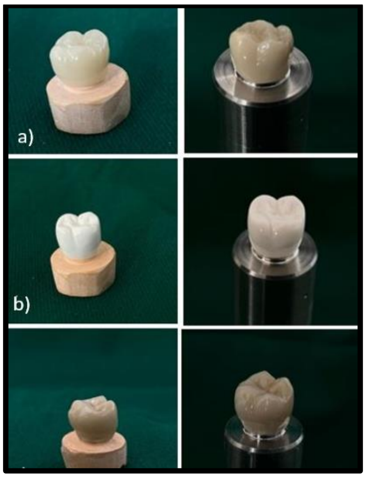


Figure 2: a. Zirconia crown b. PMMA reinforced with titanium oxide crown c. PMMA reinforced with graphene oxide crown

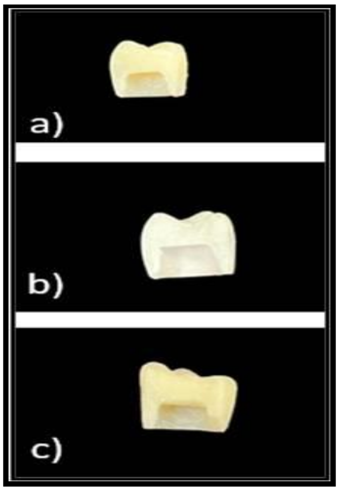


Figure 3: a. fractured zirconia crown, b. fractured PMMA reinforced with titanium oxide crown and c. fractured PMMA reinforced with graphene oxide crown

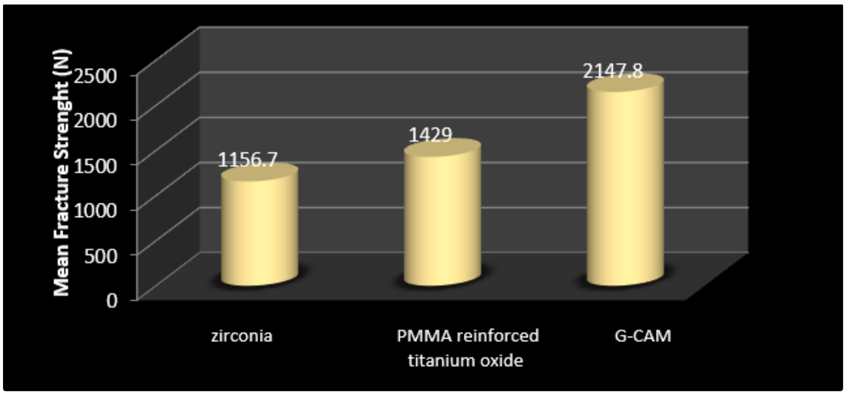


Figure 4: Comparison of mean fracture strength of Zirconia, PMMA reinforced with titanium oxide and PMMA reinforced with graphene oxide

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Discussion

The phase of provisionalisation is crucial in fixed dental prosthesis procedures, where the selection of provisional materials must consider aesthetic, mechanical, and biological factors to ensure successful restorative treatment. Research indicates that provisional restorations often fail due to fractures, leading to patient discomfort and financial losses. Also, in certain cases provisional restorations are given for a longer period for therapeutic purposes. To address these limitations and also to improve the logitivity to provisional restoration, advancements in dental material sciences are needed. There aren't many comparable studies available because these nanoparticles are more recent than usual options. One of the most used materials for temporary prosthesis is polymethyl methacrylate, or PMMA. Its consistent and linked structure, which was created by a polymerisation process carried out at ideal temperatures and pressures, is what makes it so desirable. However, as numerous studies have shown, PMMA is not without its shortcomings in addition to its advantages. AM Di Carlo et al. [21], Diez Pascaul et al. [20], and MC Chang et al. [22] had reported problems such as hydrolytic breakdown, discolouration, and inadequate fracture resistance. In clinical settings, water sorption, temperature cycling, and repetitive stress frequently result in fractures. The absorbed water weakens the PMMA resin by acting as a plasticiser. [22] Research conducted in 2015 by Karaokutan [23] further confirmed these findings, revealing a fracture resistance of 1106 ± 134.65 N for PMMA interim prosthesis. To address these limitations, current research endeavours focus on augmenting PMMA's mechanical, biological, and physical properties. One avenue being explored involves incorporating nanoparticles like titanium oxide and graphene oxide.The studies carried out by SH Kim et al [24], Shirkavand and Moslehifrad [25] showed that titanium oxide exhibits superior mechanical and antibacterial properties compared to regular PMMA, and hence can be successfully used as interim restorative material.Nowadays, TiO_2 is regarded as an inexpensive, non-toxic, and chemically stable photocatalyst. According to Acosta-Torre et al., the use of metal oxide materials at the nanoscale for the preparation of acrylic resins enables the creation of polymers with surface and colour alterations. The latter study found that the physical characteristics of both conventional and nanopigmented PMMA revealed a decreased porosity for PMMA with TiO_2. Given that high porosities have been regarded as a significant disadvantage for PMMA in prosthodontic applications, this study implies that metal oxide nanoparticles are appropriate additions for enhancing PMMA formulations. The latter study's authors proposed that a product with well-controlled morphology can be designed with the use of nanotechnology.[25] Due to its capacity to mix with a variety of biomaterials and biomolecules, graphene oxide is a relatively new material that holds promise for improving qualities including mechanical strength, electrical conductivity, thermal stability, lightweight nature, and biocompatibility [26]. When compared to conventional PMMA specimens, graphene exhibits a fracture toughness value that is higher due to its hardness, which is approximately 200 times greater than that of steelmaking it significantly more resistant to strain, compression, and wear. This is demonstrated by studies conducted by Di Carlo et al. [21], Punset et al. [27], M Tahriri et al. [28], and numerous other authors [29, 30]. They also noted in a similar way that adding graphene nanoparticles to other dental polymers significantly enhanced their mechanical properties.The modulus of elasticity of PMMA was greatly increased by the addition of graphene oxide. PMMA's mechanical resistance to compression was enhanced by the further inclusion of graphene. The wear resistance increased and the friction coefficient decreased as a result of all these mechanical characteristics. Because the teeth's occlusal and chewing functions cause wear between materials, these characteristics are crucial for prosthetic materials. According to research by Ramanathan et al., adding more than 1% of graphene (nanosheets) increases PMMA's modulus of elasticity by 80% and its mechanical strength by 20%. [27] Our research looked at the fractural strength of acrylic resin combined with zirconia crowns, titanium oxide, and graphene oxide. In comparison to PMMA reinforced with titanium oxide and graphene oxide, the study found that PMMA modified with graphene oxide had the highest fractural strength. These findings can be attributed to two features of graphene: its high elastic modulus, which shows enhanced resistance to deformation and makes it an ideal reinforcing agent to improve the mechanical

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properties of PMMA; and its single-atom-thick sheet structure, which is arranged in a honeycomb-like lattice with each carbon atom covalently bonded to three other carbon atoms with Sp2 hybridisation. [30] Every prior study's findings [21–29] were comparable to ours, which revealed that PMMA treated with graphene oxide produced the best outcomes when compared to the other two materials..By comparing the mechanical properties, biocompatibility, and bond strength of graphene oxide with zirconia, we aim to explore the feasibility of graphene oxide as a potential alternative to zirconia for permanentdental restorations. We aim to investigate whether graphene oxide-based temporary restorations could be a feasible long-term solution by comparing the fractural strength of graphene oxide with zirconia. The results of the aforementioned investigations indicate that graphene oxide can greatly increase the fracture resistance of dental materials; however, it is unclear if this enhancement can be directly compared to the fracture resistance of materials commonly used in fixed prosthesis, like zirconia. Comparative studies directly assessing the fracture resistance of PMMA reinforced graphene oxide against zirconia would be necessary to determine their equivalence in clinical applications. Factors such as long-term durability, biocompatibility, and compatibility with existing clinical protocols would also need consideration in evaluating their suitability as a replacement for fixed prosthetic materials. This investigation holds significant promise for revolutionizing dental prosthetics by offering a novel material that combines the aesthetic appeal of zirconia with the versatility and cost-effectiveness of graphene.

Conclusion

The fracture strengths of zirconia, PMMA reinforced with titanium dioxide, and PMMA reinforced with graphene oxide crowns were compared in this study. PMMA with graphene oxide outperformed PMMA containing titanium dioxide and zirconia in terms of mean fracture strength. These findings imply that PMMA enhanced with graphene oxide may be a suitable material for long-term temporary restorative applications in prosthodontics. In general, this study argues in favour of using graphene oxide in dental materials as a strengthening agent. Graphene oxide-based materials have the potential to revolutionise prosthodontic practice by providing long-lasting, aesthetically pleasing, and reasonably priced interim restoration treatments with further study and development.

References

1. Ferro KJ, Morgano SM, Driscoll CF, Freilich MA, Guckes AD, Knoernschild KL, McGarry TJ, Photography NA, Twain M. The glossary of prosthodontic terms.2017.9th Edition.
2. Rayyan MM, Aboushelib M, Sayed NM, Ibrahim A, Jimbo R. Comparison of interim restorations fabricated by CAD/CAM with those fabricated manually. The Journal of prosthetic dentistry. 2015 Sep 1;114(3):414-9.
3. Lodding DW. Long-term esthetic provisional restorations in dentistry. Current opinion in cosmetic dentistry. 1997 Jan 1;4:16-21.
4. Miura, S.; Fujisawa, M.; Komine, F.; Maseki, T.; Ogawa, T.; Takebe, J.; Nara, Y. Importance of interim restorations in the molar region. J. Oral Sci. 2019, 61, 195–199
5. Ruse, N.D.; Sadoun, M.J. Resin-composite Blocks for Dental CAD/CAM Applications. J. Dent. Res. 2014, 93, 1232–1234.
6. Skorulska A, Piszko P, Rybak Z, Szymonowicz M, Dobrzyński M. Review on polymer, ceramic and composite materials for cad/cam indirect restorations in dentistry—Application, mechanical characteristics and comparison. Materials. 2021 Mar 24;14(7):1592.
7. Alp G, Murat S, Yilmaz B. Comparison of flexural strength of different CAD/CAM PMMA-based polymers. Journal of Prosthodontics. 2019 Feb;28(2):e491-5.
8. Ruse ND, Sadoun MJ. Resin-composite blocks for dental CAD/ CAM applications. J Dent Res. 2014;93:1232-4
9. Matsuo H, Suenaga H, Takahashi M, Suzuki O, Sasaki K, Takahashi N. Deterioration of polymethyl methacrylate dentures in the oral cavity. Dental materials journal. 2015 Mar 27;34(2):234-9.
10. Haselton DR, Diaz-Arnold AM, Vargas MA. Flexural strength of provisional crown and fixed partial denture resins. J Prosthet Dent. 2002;87:225-8.
11. Al-Saleh S, Alateeq A, Alshaya AH, Al-Qahtani AS, Tulbah HI, Binhasan M, Shabib S, Farooq I, Vohra F, Abduljabbar T. Influence of TiO2 and ZrO2 nanoparticles on adhesive bond strength and viscosity of dentin polymer: A physical and chemical evaluation. Polymers. 2021 Nov 2;13(21):3794.
12. Meyer JC, Geim AK, Katsnelson MI, Novoselov KS, Booth TJ, Roth S. The structure

of suspended graphene sheets. Nature. 2007;446:60-3.
13. Williams AG, Moore E, Thomas A, Johnson JA. Graphene-Based Materials in Dental Applications: Antibacterial, Biocompatible, and Bone Regenerative Properties. Int J Biomater. 2023 Feb 7;2023:8803283.
14. Dubey N, Ellepola K, Decroix FED, Morin JLP, Castro Neto AH, Seneviratne CJ, Rosa V. Graphene onto medical grade titanium: an atom-thick multimodal coating that promotes osteoblast maturation and inhibits biofilm formation from distinct species. Nanotoxicology. 2018;12(4):274- 89.
15. Ahmed, J., Shahzad, A., Farooq, A., Kamran, M., Ud-Din Khan, S., & Ud-Din Khan, S. (2021). Thermal analysis in swirling flow of titanium dioxide–aluminum oxide water hybrid nanofluid over a rotating cylinder. Journal of Thermal Analysis and Calorimetry, 144(6), 2175-2185.
16. Naheed S, Shahid M, Zahoor R, Siddique Z, Rasool N, Haider S, Khan S. Synthesis and study of morphology and biocompatibility of xanthan gum/titanium dioxide-based polyurethane elastomers. Polymers. 2021 Oct 5;13(19):3416.
17. Mehrpour H, Farjood E, Giti R, Ghasrdashti AB, Heidari H. Evaluation of the flexural strength of interim restorative materials in fixed prosthodontics. Journal of Dentistry. 2016 Sep;17(3):201.
18. Shelar P, Abdolvand H, Butler S. On the behaviour of zirconia-based dental materials: a review. Journal of the Mechanical Behavior of Biomedical Materials. 2021 Dec 1;124:104861..
19. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. Journal of prosthodontic research. 2013;57(4):236-61.
20. Díez-Pascual AM. PMMA-Based Nanocomposites for Odontology Applications: A State-of-the-Art. International Journal of Molecular Sciences. 2022; 23(18):10288.
21. Di Carlo S, De Angelis F, Brauner E, Pranno N, Tassi G, Senatore M, Bossù M. Flexural strength and elastic modulus evaluation of structures made by conventional PMMA and PMMA reinforced with graphene. Eur Rev Med Pharmacol Sci. 2020 May;24(10):5201-5208.
22. Chang MC, Hung CC, Chen WC, Tseng SC, Chen YC, Wang JC. Effects of pontic span and fiber reinforcement on fracture strength of multi-unit provisional fixed partial dentures. J Dent Sci. 2019 Sep;14(3):309-317
23. Karaokutan I, Sayin G, Kara O. In vitro study of fracture strength of provisional crown materials. The journal of advanced prosthodontics. 2015 Feb;7(1):27.
24. Kim SH, Watts DC. The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high-impact acrylic resin. The journal of prosthetic dentistry. 2004 Mar 1;91(3):274-80.
25. Shirkavand S., Moslehifard E. Effect of TiO2 nanoparticles on tensile strength of dental acrylic resins. Journal of Dental Research, Dental Clinics, Dental Prospects . 2014;8(4):197–203.
26. Lee JH, Jo JK, Kim DA, Patel KD, Kim HW, Lee HH. Nano-graphene oxide incorporated into PMMA resin to prevent microbial adhesion. Dent Mater. 2018 Apr;34(4):e63-e72.
27. Punset M, Brizuela A, Pérez-Pevida E, Herrero-Climent M, Manero JM, Gil J. Mechanical characterization of dental prostheses manufactured with PMMA–graphene composites. Materials. 2022 Aug 5;15(15):5391.
28. Tahriri M, Del Monico M, Moghanian A, TavakkoliYaraki M, Torres R, Yadegari A, Tayebi L. Graphene and its derivatives: Opportunities and challenges in dentistry. Mater Sci Eng C Mater Biol Appl. 2019 Sep;102:171-185.
29. Jiang N, Tan P, He M, Zhang J, Sun D, Zhu S. Graphene reinforced polyether ether ketone nanocomposites for bone repair applications. Polymer Testing. 2021 Aug 1;100:107276.
30. Alamgir M, Nayak GC, Mallick A, Tiwari SK, Mondal S, Gupta M. Processing of PMMA nanocomposites containing biocompatible GO and TiO2 nanoparticles. Materials and Manufacturing Processes. 2018 Sep 10;33(12):1291-8.