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TO ASSESS AND COMPARE THE IMPACT OF TITANIUM DIOXIDE NANOPARTICLES AND CARBON FIBERS ON THE FLEXURAL STRENGTH OF REPAIRED DENTURES FRACTURE

Amrinder S Mattu[1*], Vaishnavi N Vashi[2], Patricia Marian[3], Arun Vashisht[4], Rashi Dadhich[5]

[1*]BDS, Dasmesh Institute of Research and Dental Sciences, Faridkot, Punjab, India.
[2]BDS, Dharmsinh Desai University, Nadiad, Gujarat, India.
[3]BDS, Malabar Dental College and Research Centre, Vattamkula, Kerala, India.
[4]BDS, MDS, PG Prosthodontics, Director, Gimme Smile, PPLC, Texas, North America
[5]BDS, Modern Dental College and Research Centre, Indore, MP, India.

***Corresponding Author:** Amrinder S Mattu
*BDS, Dasmesh Institute of Research and Dental Sciences, Faridkot, Punjab, India.

Abstract

This study investigates the impacts of titanium dioxide nanoparticles (TiO_2 NPs) and carbon fibers on the flexural strength of repaired denture fractures. Dentures frequently suffer from fractures, necessitating effective repair strategies to restore their structural integrity. The inclusion of advanced materials like TiO_2 NPs and carbon fibers has shown promise in enhancing mechanical properties. The experimental procedures involved the repair of fractured denture specimens using acrylic resin composites reinforced with TiO_2 NPs or carbon fibers. Following standardized protocols, the repaired specimens were subjected to flexural strength testing using a three-point bending test to simulate masticatory forces.

The results demonstrated that TiO_2 NPs and carbon fibers significantly improved the flexural strength of repaired dentures compared to unreinforced acrylic resin repairs. The carbon fiber reinforcement yielded higher improvement in flexural strength than TiO_2 NP, possibly due to enhanced interfacial bonding and load distribution capabilities. On the other hand, TiO_2 NPs provided significant benefits like high biocompatibility and aesthetics.

In conclusion, these findings highlight the potential of both materials in advancing dental repair technologies, providing pathways for durable and functionally resilient denture repairs. Future research should explore long-term durability and biocompatibility in vivo to fully validate their clinical efficacy.

Keywords: Titanium Dioxide nanoparticles (TiO_2 NPs), Carbon fibers, flexural strength, denture fractures

The growing prevalence of denture use among aging populations underscores the importance of developing reliable methods to repair denture fractures. Denture fractures typically occur due to material fatigue, accidental drops, and improper handling, leading to compromised functionality and increased patient discomfort. Traditional repair methods using acrylic resin have proven effective; however, enhancing the structural integrity to prevent recurrent fractures remains a significant challenge. Incorporating advanced materials like TiO_2 NPs and carbon fibers offers promising avenues to improve the flexural strength of repaired dentures.[1-3]

TiO_2 NPs have garnered considerable attention in the dental field because of their unique properties like excellent biocompatibility, high surface area, and enhanced mechanical properties. Their addition to dental composites can potentially improve the mechanical strength and durability of the material. Studies suggest that nano-reinforcement results in better stress distribution and resistance to crack propagation, critical factors in maintaining the integrity of repaired dentures under functional loads.[4-6]

On the other hand, Carbon fibers are well known for their exceptional mechanical properties, including high tensile strength, stiffness, and excellent fatigue resistance. These characteristics make carbon fibers ideal for reinforcing dental materials, potentially transforming the structural resilience of repaired dentures. Integrating carbon fibers into acrylic resin has been shown to distribute applied stress more effectively, thus enhancing the composite material's overall strength and reducing the likelihood of failure under repeated mechanical stresses.[7,8]

This study aims to assess and compare the effects of TiO_2 NPs and carbon fibers on the flexural strength of repaired denture fractures. Through empirical evaluation, we seek to determine the optimal reinforcement method that can restore and potentially exceed the original strength of fractured dentures, ensuring prolonged functional performance and patient satisfaction.

In this experimental analysis, we repaired fractured denture specimens using acrylic resin composites reinforced separately with TiO_2 NPs and carbon fibers. Standardized testing protocols were employed, including three-point bending tests, to simulate the forces experienced by dentures during mastication. By quantitatively measuring the flexural strength of each repaired specimen, we aim to elucidate the comparative effectiveness of these advanced materials.

Prior research has documented the individual benefits of TiO_2 NPs and carbon fibers; however, direct comparisons of denture repair are limited. This study bridges this gap by comprehensively analyzing the influenza of each material on the flexural performance of repaired dentures. Additionally, we have considered and discussed other aspects like ease of incorporation, cost-effectiveness, potential impacts on aesthetics, and biocompatibility to offer a holistic view of the practical implications of these reinforcement materials.

In conclusion, by identifying the superior reinforcement material for denture repairs, this research aims to contribute significantly to the field of prosthodontics. Improved denture repair techniques would improve the clinical outcomes for patients and decrease the frequency of repair procedures, resulting in a higher quality of life for denture users. Future investigations should expand upon these findings by exploring long-term wear studies and in vivo assessments to fully validate the clinical applicability of TiO_2 NPs and carbon fiber reinforcements.

Material and Method

In this experimental study, each experimental group consisted of 10 samples.

Sample Preparation

A total of 30 wax patterns were fabricated using Modelling wax, each of approximate dimensions 65 x 10 x 3 mm, following the American Dental Association Specification Number 12. Further, heat-cured acrylic resin (DPI heat cure) was prepared following the guideline by the manufacturer, combining 2 grams of powder with 1 milliliter of liquid. During the dough stage, the material was placed in a mold designed to dimensions of 65 x 2.5 x 10 mm. The molds were then closed and subjected to bench press for 30 minutes. Subsequently, the clamped molds were placed in a thermostatically controlled polymerization unit and underwent polymerization in water for 30 minutes at 60°C followed by 1 hour at 100°C. After completion of the curing cycle, the molds were allowed to cool on the bench for 24 hours. Later, the samples were retrieved, finished, and polished using a carbide bur and 600-grit silicon carbide paper under water irrigation. All 30 heat-cured acrylic samples were fractured using a compressive strength instrument. Two pieces of each fractured sample were collected, and the fracture edges were ground with a carbide bur to create a 3 mm space for the application of self-cure acrylic resin.

Group 1

Ten fractured acrylic resin samples with round surface joints were treated with monomer to enhance adhesion and wettability and later reinserted into the mold space formed during the acrylisation process. Self-cure acrylic resin (DPI cold cure) was prepared following the guideline by the manufacturer (2g powder with 1 g liquid) and applied in the 3mm gap between the fractured pieces.

Group 2

Ten fractured acrylic resin samples with round surface joints were also treated with monomer to improve adhesion and wettability and then reinserted into the mold space formed during the acrylisation. Titanium dioxide nanoparticles (1 wt%) were weighted precisely using a digital weighing scale (MH-series Pocket scale, 200g*0.01g) and thoroughly mixed with the acrylic powder using a spatula before mixing it with the monomer. The polymer and TiO_2 NP suspension were mixed manually with the monomer immediately to prevent particle aggregation. It was mixed continuously for approximately 3 minutes to achieve a doughlike consistency, making it suitable to be handled and packed into the joint space.

Group 3

Ten fractured acrylic resin samples with round surface joints were also treated with monomer to improve adhesion and wettability and then reinserted into the mold space formed during the acrylisation. Later, using carbide burr on the broken edges of the acrylic samples, slots were created that measured roughly 2.5 by 40 mm for placing fibers. Furthermore, for five minutes, fibers were soaked in the monomer. Later, soaked carbon fibers were placed in the slot of fractured edges. Subsequently, self-cure acrylic resin (DPI cold cure) was packed in the 3mm container after being prepared following the guideline by the manufacturer (2 g of powder and 1 g of liquid). Finally, after taking the specimen out of the molds, the surfaces were polished using 800-, 400-, and 200-grit sandpaper and carbide bur.

Statistical analysis

The statistical analysis was conducted utilizing the Statistical Package for Social Sciences [SPSS] for Windows, Version 24. A one-way ANOVA was performed, complemented by Tukey's post hoc analysis, to compare the flexural and impact strength across three experimental groups. The threshold for statistical significance was established at $P<0.05$. The statistical analysis revealed significant differences in the mean flexural strength and impact strength among the three groups.

Result

Table 1 delineates the comparative mean flexural strength values across the different groups. The findings indicate that the mean flexural strength for Group 1 was 330.11 ± 38.34, for Group 2 was 441.34 ± 34.14, and for Group 3 was 995.10 ± 55.14. These results suggest that Group 3 exhibited the highest mean flexural strength, followed by Group 2, while Group 1 demonstrated the lowest mean flexural strength.

Table 1 Comparison of mean Flexural Strength (in Kg/ sq cm) between different groups

Groups	Sample size	Mean ± SD	p-Value
Group 1	10	330.11 ± 38.34	0.001*
Group 2	10	441.34 ± 34.14	0.001*
Group 3	10	995.10 ± 55.14	0.001*

*Significant

Discussion

Due to the material's low flexural strength, both midline and impact failures have been identified as the primary causes of clinical failure for acrylic dentures. These clinical limitations necessitate the reinforcement of prostheses to enhance their durability and longevity. A previous independent study reported that 68% of denture fractures occurred nearly three years after the first use of the appliance, while 28% of fractures happened after just one year. Furthermore, 39% of dentures required repair within three years.[9-12]

To conquer this challenge, numerous materials have been utilized to reinforce polymers and increase their flexural strength and impact resistance; among these materials are glass, polyurethane, aramid fiber, and metal wires, available in various forms such as particles, flakes, fibers, or fabrics. The force determining a denture's resistance to fracture is termed flexural strength, and improving this characteristic has been the main focus of denture reinforcement.[13-16]

A notable study revealed that incorporating titanium dioxide nanoparticles (TiO_2 NPs) into heat-cured acrylic (PMMA) resins significantly increased the resins' flexural strength compared to the control groups. The orientation of the reinforcing fibers plays a crucial role; placing the fibers parallel to the sample's long axis provides substantial support. This orientation enhances the material's flexural strength, thus preventing midline fractures and making the denture more durable.[17-19]

While carbon fibers have been considered for reinforcement due to their strength, they pose aesthetic challenges. The primary drawback of carbon fibers is their black color, which is generally unattractive and potentially visible in the dentures. Therefore, further clinical research is essential to explore ways of incorporating fibers in areas less perceptible to the patient, such as the lingual area of the lower denture and the palatal area of the maxillary denture. These strategic placements can maintain the aesthetic appearance while providing the necessary reinforcement to withstand functional stresses.[20-22]

Overall, improving the flexural strength of denture materials through incorporating various reinforcing agents such as TiO_2 NPs and optimally positioned fibers holds promise for extending the functional lifespan of dentures and reducing fracture incidents. Continued research and innovation in this field could lead to more durable and aesthetically pleasing dental prostheses, ultimately enhancing patient satisfaction and clinical outcomes.

Conclusion

Within the scope of the study, it can be concluded that the fractured acrylic samples repaired with different materials showed varying strengths. Group 3 samples reinforced with carbon fibers demonstrated the highest mean flexural strength, followed by Group 2 samples reinforced with 1wt% titanium dioxide nanoparticles, and the control group showed the lowest strength.

References

1. Takamiya, A. S., Monteiro, D. R., Marra, J., Compagnoni, M. A., & Barbosa, D. B. (2012, June). Complete denture wearing and fractures among edentulous patients treated in university clinics. *Gerodontology*, *29*(2). https://doi.org/10.1111/j.1741-2358.2011.00551.x
2. Mubarak, S., Hmud, A., Chandrasekharan, S., & Ali, A. A. (2015). Prevalence of denture-related oral lesions among patients attending College of Dentistry, University of Dammam: A clinico-pathological study. *Journal of International Society of Preventive and Community Dentistry*, *5*(6), 506. https://doi.org/10.4103/2231-0762.170525
3. Temizci, T., & Bozoğulları, H. N. (2024). Effect of thermal cycling on the flexural strength of 3-D printed, CAD/CAM milled and heat-polymerized denture base materials. *BMC Oral Health*, *24*(1). https://doi.org/10.1186/s12903-024-04122-y
4. Liu, S., Chen, X., Yu, M., Li, J., Liu, J., Xie, Z., Gao, F., & Liu, Y. (2022, June). Applications of titanium dioxide nanostructure in stomatology. *Molecules*, *27*(12), 3881. https://doi.org/10.3390/molecules27123881

5. Besinis, A., Hadi, S. D., Le, H. R., Tredwin, C., & Handy, R. D. (2017). Antibacterial activity and biofilm inhibition by surface modified titanium alloy medical implants following application of silver, titanium dioxide and hydroxyapatite nanocoatings. *Nanotoxicology*, *11*(3), 327–338. https://doi.org/10.1080/17435390.2017.1299890
6. Huang, Y., Song, G., Chang, X., Wang, Z., Zhang, X., Han, S., Su, Z., Yang, H., Yang, D., & Zhang, X. (2018). Nanostructured Ag(+)-Substituted Fluorhydroxyapatite-TiO_2 Coatings for Enhanced Bactericidal Effects and Osteoinductivity of Ti for Biomedical Applications. *International Journal of Nanomedicine*, *Volume 13*, 2665–2684. https://doi.org/10.2147/ijn.s162558
7. Rajak, D. K., Wagh, P. H., & Linul, E. (2021, October 28). Manufacturing Technologies of Carbon/Glass Fiber-Reinforced Polymer Composites and their Properties: A review. *Polymers*, *13*(21), 3721. https://doi.org/10.3390/polym13213721
8. Miyairi, H., Nagai, M., & Takayama, Y. (1983, December). Application of carbon fiber (CF)-cloth reinforcement to upper complete denture base. *Bull Tokyo Med Dent University*;30(4), 109-17.https://pubmed.ncbi.nlm.nih.gov/6589087/
9. Hargreaves AS. The prevalence of fractured dentures, a survey. Br Dent J 1969; 126: 451-455.
10. Alla, R. K., Sajjan, S., Alluri, V. R., Ginjupalli, K., & Upadhya, N. (2013). Influence of fiber reinforcement on the properties of denture base resins. *Journal of Biomaterials and Nanobiotechnology*, *04*(01), 91–97. https://doi.org/10.4236/jbnb.2013.41012
11. Uzun, G., Hersek, N., & Tinçer, T. (1999). Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. *the Journal of Prosthetic Dentistry*, *81*(5), 616–620. https://doi.org/10.1016/s0022-3913(99)70218-0
12. Ranganath, L. M., Shet, R. G. K., & Rajesh, A. G., & Abraham, S. (2011). The Effect of Fiber Reinforcement on the Dimensional Changes of Poly Methyl Methacrylate Resin after Processing and after Immersion in Water: An in vitro Study. *the Journal of Contemporary Dental Practice*, *12*(4), 305–317. https://doi.org/10.5005/jp-journals-10024-1051
13. Mansour, M. M., Wagner, W. C., & Chu, T. G. (2013). Effect of Mica reinforcement on the flexural strength and microhardness of polymethyl methacrylate denture resin. *Journal of Prosthodontics*, *22*(3), 179–183. https://doi.org/10.1111/j.1532-849x.2012.00923.x
14. Kim, S. H., & Watts, D. C. (2004). 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*, *91*(3), 274–280. https://doi.org/10.1016/j.prosdent.2003.12.023
15. Agha, H., Flinton, R., & Vaidyanathan, T. (2016). Optimization of Fracture Resistance and Stiffness of Heat-Polymerized High Impact Acrylic Resin with Localized E-Glass FiBER FORCE® Reinforcement at Different Stress Points. *Journal of Prosthodontics*, *25*(8), 647–655. https://doi.org/10.1111/jopr.12477
16. Praveen, B., Babaji, H. V., Prasanna, B. G., Rajalbandi, S. K., Shreeharsha, T. V., & Prashant, G. M. (2014). Comparison of Impact Strength and Fracture Morphology of Different Heat Cure Denture Acrylic Resins: An In vitro Study. *Journal of International Oral Health*, 6(5), 12-16. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4229820/
17. Harini, P., Mohamed, K., & Padmanabhan, T. V. (2014). Effect of Titanium dioxide nanoparticles on the flexural strength of polymethylmethacrylate: An in vitro study. *Indian Journal of Dental Research*, *25*(4), 459-463. https://doi.org/10.4103/0970-9290.142531
18. Tandra, E., Wahyuningtyas, E., & Sugiatno, E. (2018). The effect of nanoparticles TiO2 on the flexural strength of acrylic resin denture plate. *Padjajaran Journal of Dentistry*, *30*(1), 35-40. https://doi.org/10.24198/pjd.vol30no1.16110
19. Karci, M., Demir, N., & Yazman, S. (2018). Evaluation of Flexural Strength of Different Denture Base Materials Reinforced with Different Nanoparticles. *Journal of Prosthodontics*, *28*(5), 572–579. https://doi.org/10.1111/jopr.12974

20. McConnell, V. P. (2010). Launching the carbon fibre recycling industry. *Reinforced Plastics*, *54*(2), 33–37. https://doi.org/10.1016/s0034-3617(10)70063-1
21. Oliveux, G., Dandy, L. O., & Leeke, G. A. (2015). Current status of recycling of fibre reinforced polymers: Review of technologies, reuse and resulting properties. *Progress in Materials Science*, *72*, 61–99. https://doi.org/10.1016/j.pmatsci.2015.01.004
22. Pimenta, S., & Pinho, S. T. (2011). Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook. *Waste Management*, *31*(2), 378–392. https://doi.org/10.1016/j.wasman.2010.09.019