RESEARCH PAPER

Mechanical Properties of TiO2 Nanoparticles Incorporated PMMA Bone Cements

Neha R[1], Balaji Ganesh S[2*], S. Jayalakshmi[3], Thebez Veda Jeyaraj Thooyamani[4], Konmireddy Vaishnavi[5]

[1]Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai - 600077, India. Email: 152001040.sdc@saveetha.com

[2*]Reader, White Lab - Materials Research Centre, Saveetha Dental College and Hospital, Saveetha Institute of Medical & Technical Sciences (SIMATS), Saveetha University, Chennai - 600077, Tamil Nadu, India. Email: balajiganeshs.sdc@saveetha.com (Corresponding Author)

[3]Professor, White Lab - Materials Research Centre, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai - 600077, Tamil Nadu, India. Email: jayalakshmisomasundaram@saveetha.com

[4]Biomedical Engineer, White Lab - Material Research Centre, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai - 600077, Tamil Nadu, India. Email: thebez1999@gmail.com

[5]Tutor, White Lab - Material Research Centre, Department of Pedodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai - 600077, Tamil Nadu, India. Email: vaishnavik.sdc@saveetha.com

ABSTRACT

INTRODUCTION: Polymethylmethacrylate is considered the most prevalent bone cement base material. Most fractures that occur during function are due to its weakness and lack of mechanical strength. The apparent limitations of PMMA are insufficient ductility, strength, and viscoelastic behavior. The current study aims to strengthen and improve PMMA bone cement properties by adding TiO2 nanoparticles. Cold-cure Acrylic powder and Methyl Methacrylate were used to produce Polymethylmethacrylate (PMMA) as the polymeric base of composite. TiO2 nano powders were used as reinforcement phase.

MATERIALS AND METHOD: PMMA bone cement samples were prepared by incorporating TiO_2 nanoparticles at varying weight percentages. Standardized specimens were fabricated and subjected to mechanical testing such as hardness and roughness. Hardness testing was carried out using a Vickers microhardness tester. The average Vickers hardness number (VHN) was calculated from multiple indentations on each sample. Surface roughness was evaluated using a surface profilometer. The average surface roughness (Ra) was measured by tracing the stylus across the sample surface over a defined length.

RESULT: The results of this study demonstrated that the PMMA-TiO2 material has greater microhardness and lesser roughness than PMMA cement. According to the test performed the difference was statistically significant.

CONCLUSION: The incorporation of TiO_2 nanoparticles into PMMA bone cement resulted in a notable improvement in surface and mechanical characteristics. The modified cement exhibited increased hardness compared to conventional PMMA, indicating enhanced resistance to deformation and wear. Additionally, a reduction in surface roughness was observed, suggesting a smoother surface profile that may minimize bacterial adhesion and improve overall material performance.

Keywords: Innovative, Sustainability, Microhardness, TiO2 Nanoparticles, PMMA Bone cements, Surface Roughness

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INTRODUCTION:

Polymethyl methacrylate (PMMA), often known as bone cement, is routinely used in orthopedic surgery for prosthesis fixation, compressive vertebral fracture stabilization, and bone defect filling(1). Bone cement is a possibly new repair material that has recently been researched in dentistry to stabilize implant prostheses due to qualities such as minimal cytotoxicity, great biocompatibility, and resistance to moisture. Bone cement can be utilized in endodontics for apexification, retrograde filling, and furcation repair(2).

PMMAs are additionally employed for unique impression trays and temporary crowns.PMMAs are also employed in non-dental applications in daily life as acrylic glass and bone cement.The fundamental building blocks of PMMA are methyl esters of methacrylic acid, however acrylics used in prosthetic dentistry also comprise a variety of additional elements(3).

Bone cement possesses numerous qualities that make it an excellent repair material for a variety of endodontic treatments. It has good strength and load-bearing capability, good handling and working properties, a 15-minute setting time, and good marginal adaptation.The bone cement is said to exhibit low cytotoxicity compared to MTA(4).

Although bone cement has a high strength, during cyclic bending and tensile stresses, the brittle nature of PMMA is revealed, and breakage occurs at significantly lower loads than the projected ultimate strength values(5). Because of the high exotherm of the polymerization reaction and the toxicity of the MMA, bone necrosis can develop. As a result, modified bone cements are developed by adding fillers, adhesives, antibiotics, and nanoparticles, making it ideally suited as an endodontic repair material to improve the: Physical characteristics, interface quality, osteoconduction, and thermal reduction.It is said that loosening of the implants is caused by the mechanical breakdown of the cement. It can be advantageous to use bone cement with increased creep resistance and fracture toughness.The contact between the bone and the cement may be strengthened by bioactivating PMMA bone cement with bioactive fillers(6).

The mechanical characteristics of PMMA bone cement are influenced by both inherent and extrinsic factors. The extrinsic factors include mixing time and speed, mixing techniques, prechilling of the monomer, and porosity levels. The monomer and powder composition, powder particle size, shape, and size distribution, and powder liquid ratio are some of the intrinsic factors(7).

Many nanoparticles, including TiO2, SiO2, ZnO, Ag, Hydroxyapatite, and carbon nanotubes, have been included into various biomaterials to activate antibacterial movement and increase mechanical conductivity(8).Due to its apparent high strength, accessibility, white shading, productivity, and low effort, TiO2 possesses qualities. TiO2 NPs are also non-toxic, synthetically inert, and exhibit antibacterial activity throughout a broad range of configurations. Numerous previous studies have shown that even the expansion of low fixation TiO2 NPs can activate new physicochemical and mechanical capabilities, resulting in another natural nanocomposite material with superior qualities(9).

TiO2 nanoparticles likewise improved the mechanical conduct of PMMA by fundamentally diminishing bacterial adherence with expanding TiO2 proportion(10). The objectives of the present study are to accomplish surface modification with TiO2 NPs and fabrication of PMMA bone cement/TiO2 nanocomposites and study the effects of TiO2 NP on the mechanical properties of the bone cements.

MATERIALS AND METHOD:

The nanocomposites were created by combining the powder component made up of prepolymerized MMA beads and initiator, with the liquid part, made up of PMMA and activator, in accordance with the typical procedure advised for creating bone cements.The cross-linked polymethylmethacrylate nanosphere-containing two-solution bone cements (n-TSBC), which served as controls, were created with a polymer to monomer ratio of 1:1 and a cross-linked PMMA nanospheres to linear PMMA ratio of 1.5:1. TiO2 nanotube samples were created utilizing Institution BS.

IS05833.002's Implants for SurgeryAcrylic Res Cements standard as a reference.

As per the manufacturer's instructions, manual mixing was performed in a polypropylene mixing bowl using a polypropylene spatula. To create samples with the desired dimensions, the Cements were poured into polytetrafluoroethylene (PIFE) molds that were clamped between stainless steel end plates. The samples were taken out of the molds after 30mm and dry-sanded using silicon carbide paper of a 400 grit to the proper dimensions.

Mechanical properties of bone cement

The primary target of this thesis was to investigate the mechanical properties of nanocomposite bone cements. In order to evaluate the long term surgical efficacy of cemented arthroplasties, two major mechanical properties of the bone cements are important, i.e. roughness and hardness. The cement layer has the main task of resisting and transferring the loads between the natural and synthetic coupled materials, while functioning as a mechanical buffer, reducing the stress concentrations and absorbing mechanical shock.

Surface Roughness Measurement

The surface roughness of the samples were measured using a stylus profilometer (Mitutoyo SJ 310R, Mitutoyo Corporation, Japan) with a 2 um tip and a 60° angle.

The stylus profilometer employs a non destructive, highly sensitive and reproducible method making it ideal for assessing how abrasion affects the surface texture of dental materials. The device was manually moved across the surface of each specimen to record baseline roughness values.

Vickers hardness tests

TiO2 impregnated nanotubes and control samples (6 mm diameter and 12 mm height) were prepared and the surfaces polished with a 400 grit silicon carbide paper. One sample of each cement brand was stored in air for 24 h at 23°C and one sample of each cement brand was stored in Ringer's solution for 60 days at 37 °C. The microhardness of the samples was tested according to the ISO 6507-2 standard (Institution BS. ISO 6507, 2005). Five indentations, 1 mm apart and 1 mm from the edges of the sample, were placed on both sides of each sample using a Shimadzu HMV-G31DT (Shimadzu HMV-G31DT Micro Vickers Hardness Tester) with a load of 200 g for 10s.

The statistical analysis performed (ANOVA) was carried out to establish significant differences between groups of samples using spss software the data analysis package in Excel (Microsoft). Significance between groups was defined as those with a calculated p-value of less than 0.05.

RESULT:

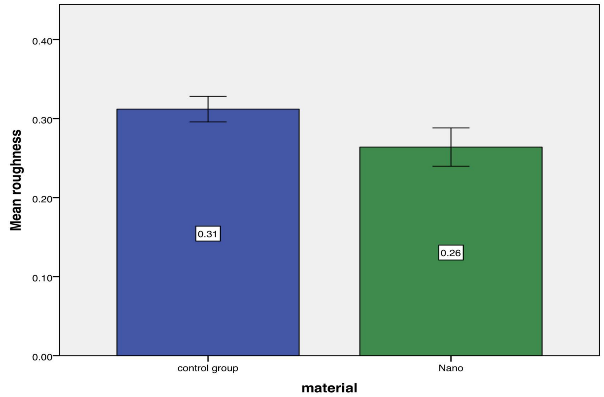

Figure 1: Bar graph represents the Mean Roughness value compared with PMMA and PMMA-TiO2 material. 'X' axis represents Mean Roughness value and the 'Y' axis represents the PMMA and PMMA-TiO2 material.

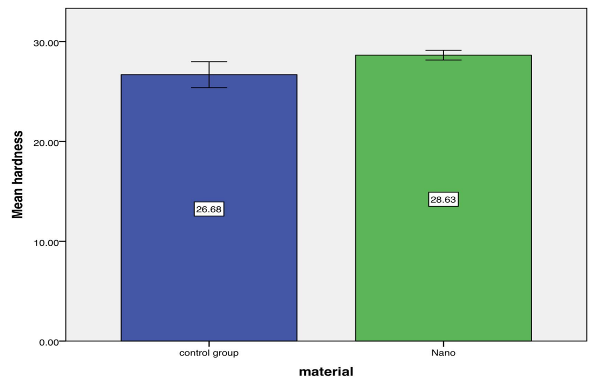

Figure 2: Bar graph represents the Mean Hardness value compared with PMMA and PMMA-TiO2 material. 'X' axis represents Mean Hardness value and the 'Y' axis represents the PMMA and PMMA-TiO2 material.

Parameter	Material	Sig.	Mean	Std. Deviation
Roughness	PMMA	.003	0.3120	0.01304
	PMMA/TiO_2		0.2640	0.01949
Hardness	PMMA	.011	26.6840	1.04593
	PMMA/TiO_2		28.6340	0.39291

From the above table The surface roughness of PMMA is 0.3120 and for the PMMA/TiO2 is 0.2604. It is observed that the PMMA/TiO2 samples have lesser surface roughness than the PMMA group. The significance testing of the surface roughness between the test and control depicted a p value of 0.003 which is less than 0.05 indicating that it is statistically insignificant.The mean value of control is 0.3120 and the

test is 0.2604 which indicates that value of control is greater than test value with a difference of 0.04800.
The mean value of microhardness for PMMA is 26.6840 and the PMMA/TiO2 is 28.6340.Increased microhardness is observed in test samples. The significance testing of surface hardness between the PMMA/TiO2 and the PMMA groups is 0.011 depicted that the p value is greater than 0.05 indicating that it is statistically significant. The mean value of the test is 28.6340 and that of the control is 26.6840 indicating that test value is greater than that of control with a difference of 1.95000.

DISCUSSION:

The present study evaluated the influence of TiO_2 nanoparticle incorporation on the surface and mechanical properties of PMMA bone cement, with particular emphasis on hardness and surface roughness. The results demonstrated a **significant increase in hardness** and a **reduction in surface roughness** in PMMA/TiO_2 composites compared to conventional PMMA bone cement(11).
The enhancement in hardness can be attributed to the **reinforcing effect of TiO_2 nanoparticles** within the PMMA matrix. Due to their high surface area and intrinsic mechanical strength, these nanoparticles act as effective fillers that restrict polymer chain mobility and improve resistance to localized plastic deformation(12). This leads to higher resistance to indentation, as observed in the increased Vickers hardness values. Additionally, the uniform dispersion of nanoparticles at optimal concentrations facilitates efficient stress transfer between the matrix and the filler, further contributing to improved mechanical performance.The observed results are in accordance with a lot of earlier research for different nanomaterials(13). Mechanical behavior of PMMA bio-polymer was improved with some nano additives. In (14), the improvement of various injectable materials can be obtained by using nanomaterials (Ag, Cu, Ni, AgCu) (15).
With respect to **surface hardness**, the results of this study are in strong agreement with earlier research. Multiple studies have consistently reported that the addition of TiO_2 nanoparticles enhances the hardness of PMMA due to increased stiffness and reduced polymer chain mobility. For instance, studies have shown that hardness can increase by up to **18–35% with 1–3 wt% TiO_2 incorporation**, attributed to improved filler–matrix interaction and restriction of molecular movement . Similarly, literature reviews confirm that even low concentrations (≈1–3 wt%) significantly improve hardness due to the reinforcing effect of rigid nanoparticles . Therefore, the increase in hardness observed in the present study is consistent with the widely accepted mechanism of nanoparticle reinforcement(16).
The observed decrease in surface roughness in the PMMA/TiO_2 group is an important finding. The incorporation of nanosized TiO_2 particles likely results in a **more compact and homogeneous microstructure**, reducing surface irregularities(17). Furthermore, during polishing, the presence of well-dispersed nanoparticles may help in achieving a smoother finish compared to conventional PMMA(18). A smoother surface is clinically advantageous, as it may **reduce bacterial adhesion and biofilm formation**, thereby lowering the risk of post-surgical infection(19)
In contrast, the findings related to **surface roughness** show some variation when compared to previous studies. While the present study observed a **decrease in surface roughness**, several earlier investigations have reported an **increase in roughness** following TiO_2 incorporation, especially at higher concentrations or with particle sizes below 50 nm (20). This increase has been attributed to nanoparticle agglomeration and poor dispersion, which can create surface irregularities. However, other studies suggest that proper dispersion techniques and optimal nanoparticle concentrations can lead to a **more homogeneous and smoother surface**, aligning with the results of the current study.
The statistical analysis ($p = 0.003$) indicates that the reduction in surface roughness is **highly significant**, confirming that the improvement is not due to random variation. The mean difference observed between the groups further supports the effectiveness of TiO_2 incorporation in modifying surface characteristics(21).
However, it is important to consider that the beneficial effects of nanoparticles are highly dependent on their concentration and dispersion. While lower concentrations improve properties, excessive loading may lead to **nanoparticle agglomeration**, creating stress concentration points that could negatively affect mechanical integrity. Although this study focused on selected concentrations, optimization remains crucial for achieving the best balance of properties(22).

CONCLUSION:

The present study demonstrates that the incorporation of TiO_2 nanoparticles into PMMA bone cement significantly enhances its surface and mechanical properties. The modified PMMA/TiO_2 cement exhibited **increased hardness**, indicating improved resistance to deformation and wear, along with a **significant reduction in surface roughness**, reflecting a smoother and more homogeneous surface profile compared to conventional PMMA.Overall, TiO_2-reinforced PMMA bone cement shows promising potential as an improved biomaterial for orthopedic use. Further studies focusing on long-term performance and biocompatibility are recommended to validate its clinical applicability.

Limitations of the present study include the non clinically relevant manner in which the cement powder and liquid monomer were mixed without following the vacuum mixing method. Moreover, omission of determining the fatigue life, fatigue crack propagation resistance and long-term wear of the cements limits its immediate applicability and necessitates future work. However, the improvement in fracture toughness indicates a possible improvement in the fatigue life

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CONFLICT OF INTEREST:

The authors would like to declare no conflict of interest in the present study.

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REFERENCES:

- Vollrath A, Pretzel D, Pietsch C, Perevyazko I, Schubert S, Pavlov GM, et al. Preparation, cellular internalization, and biocompatibility of highly fluorescent PMMA nanoparticles. Macromol Rapid Commun [Internet]. 2012 Oct 26;33(20):1791–7. Available from: http://dx.doi.org/10.1002/marc.201200329
- Yunus N, Harrison A, Huggett R. Effect of microwave irradiation on the flexural strength and residual monomer levels of an acrylic resin repair material. J Oral Rehabil [Internet]. 1994 Nov;21(6):641–8. Available from: http://dx.doi.org/10.1111/j.1365-2842.1994.tb01179.x
- Lissarrague MH, Fascio ML, Goyanes S, D'Accorso NB. Acrylic Bone Cements: The Role of Nanotechnology in Improving Osteointegration and Tunable Mechanical Properties [Internet]. Vol. 10, Journal of Biomedical Nanotechnology. 2014. p. 3536–57. Available from: http://dx.doi.org/10.1166/jbn.2014.2045
- Mousa WF, Kobayashi M, Shinzato S, Kamimura M, Neo M, Yoshihara S, et al. Biological and mechanical properties of PMMA-based bioactive bone cements. Biomaterials [Internet]. 2000 Nov;21(21):2137–46. Available from: http://dx.doi.org/10.1016/s0142-9612(00)00097-1
- Urban VM, Machado AL, Vergani CE, Giampaolo ET, Pavarina AC, de Almeida FG, et al. Effect of water-bath post-polymerization on the mechanical properties, degree of conversion, and leaching of residual compounds of hard chairside reline resins. Dent Mater [Internet]. 2009 May;25(5):662–71. Available from: http://dx.doi.org/10.1016/j.dental.2008.10.017
- Gautam R, Singh RD, Sharma VP, Siddhartha R, Chand P, Kumar R. Biocompatibility of polymethylmethacrylate resins used in dentistry. J Biomed Mater Res B Appl Biomater [Internet]. 2012 Jul;100(5):1444–50. Available from: http://dx.doi.org/10.1002/jbm.b.32673
- Khandaker M, Vaughan M, Morris T, White J, Meng Z. Effect of additive particles on mechanical, thermal, and cell functioning properties of poly(methyl methacrylate) cement [Internet]. International Journal of Nanomedicine. 2014. p. 2699. Available from: http://dx.doi.org/10.2147/ijn.s61964
- Bayraktar G, Guvener B, Bural C, Uresin Y. Influence of polymerization method, curing process, and length of time of storage in water on the residual methyl methacrylate content in dental acrylic resins. J Biomed Mater Res B Appl Biomater [Internet]. 2006 Feb;76(2):340–5. Available from: http://dx.doi.org/10.1002/jbm.b.30377
- Barralet JE, Gaunt T, Wright AJ, Gibson IR, Knowles JC. Effect of porosity reduction by compaction on

compressive strength and microstructure of calcium phosphate cement. J Biomed Mater Res [Internet]. 2002;63(1):1–9. Available from: http://dx.doi.org/10.1002/jbm.1074

- Khaled SMZ, Charpentier PA, Rizkalla AS. Physical and mechanical properties of PMMA bone cement reinforced with nano-sized titania fibers. J Biomater Appl [Internet]. 2011 Feb;25(6):515–37. Available from: http://dx.doi.org/10.1177/0885328209356944
- Zebarjad SM, Sajjadi SA, Ebrahimi Sdrabadi T, Sajjadi SA, Yaghmaei A, Naderi B. A Study on Mechanical Properties of PMMA/Hydroxyapatite Nanocomposite [Internet]. Vol. 03, Engineering. 2011. p. 795–801. Available from: http://dx.doi.org/10.4236/eng.2011.38096
- G S, Balaji Ganesh S, Kumar R, Kaarthikeyan G. In-vitro evaluation of multicomponent scaffold with kappa carrageenan, tendon extracellular matrix and calcium-magnesium silicate for periodontal bone regeneration. J Oral Biol Craniofac Res [Internet]. 2025 Aug 13;15(6):1260–5. Available from: http://dx.doi.org/10.1016/j.jobcr.2025.08.011
- Lukaszczyk J, Smiga-Matuszowicz M. Polymer and composite bone cements and related materials. Part II. Resorbable and bioactive compositions [Internet]. Vol. 55, Polimery. 2010. p. 83–92. Available from: http://dx.doi.org/10.14314/polimery.2010.083
- Heller MO, Bergmann G, Kassi JP, Claes L, Haas NP, Duda GN. Determination of muscle loading at the hip joint for use in pre-clinical testing. J Biomech [Internet]. 2005 May;38(5):1155–63. Available from: http://dx.doi.org/10.1016/j.jbiomech.2004.05.022
- Chen L, Tang Y, Zhao K, Zha X, Liu J, Bai H, et al. Fabrication of the antibiotic-releasing gelatin/PMMA bone cement. Colloids Surf B Biointerfaces [Internet]. 2019 Nov 1;183:110448. Available from: http://dx.doi.org/10.1016/j.colsurfb.2019.110448
- Vohra M, Maiti S, Shah KK, Raju L, Nallaswamy D, Eswaramoorthy R. Influence of L-arginine on hydroxyapatite-based ovine bone graft - An evaluation of surface characteristics and cell viability. Dent Res J (Isfahan) [Internet]. 2025 May 22;22:19. Available from: http://dx.doi.org/10.4103/drj.drj_263_24
- Rajendran J, Sundramoorthy AK, Ganapathy D, Atchudan R, Habila MA, Nallaswamy D. 2D MXene/graphene nanocomposite preparation and its electrochemical performance towards the identification of nicotine level in human saliva. J Hazard Mater [Internet]. 2022 Oct 15;440:129705. Available from: http://dx.doi.org/10.1016/j.jhazmat.2022.129705
- Arora O, Ahmed N, Nallaswamy D, Ganapathy D, Srinivasan M. Denture base materials: An in vitro evaluation of the mechanical and color properties. J Dent [Internet]. 2024 Jun;145:104993. Available from: http://dx.doi.org/10.1016/j.jdent.2024.104993
- Pahlevanzadeh F, Bakhsheshi-Rad HR, Hamzah E. In-vitro biocompatibility, bioactivity, and mechanical strength of PMMA-PCL polymer containing fluorapatite and graphene oxide bone cements [Internet]. Vol. 82, Journal of the Mechanical Behavior of Biomedical Materials. 2018. p. 257–67. Available from: http://dx.doi.org/10.1016/j.jmbbm.2018.03.016
- V A, Rajaraman V, Ariga P, Nallaswamy D. Maxillofacial Reconstruction With Three Dimensional Resin Bone Substitutes as an Alternative to Transition Group of Metals: A Structured Review. Cureus [Internet]. 2024 Apr;16(4):e57396. Available from: http://dx.doi.org/10.7759/cureus.57396
- Souza TAJ, Franchi LP, Rosa LR, da Veiga MAMS, Takahashi CS. Cytotoxicity and genotoxicity of silver nanoparticles of different sizes in CHO-K1 and CHO-XRS5 cell lines. Mutat Res Genet Toxicol Environ Mutagen [Internet]. 2016 Jan 1;795:70–83. Available from: http://dx.doi.org/10.1016/j.mrgentox.2015.11.002
- Russo T, Gloria A, De Santis R, D'Amora U, Balato G, Vollaro A, et al. Preliminary focus on the mechanical and antibacterial activity of a PMMA-based bone cement loaded with gold nanoparticles. Bioact Mater [Internet]. 2017 Sep;2(3):156–61. Available from: http://dx.doi.org/10.1016/j.bioactmat.2017.05.002