AL-KUNOOZE SCIENTIFIC JOURNAL
ISSN: 2706-6231 E ,2706-6223 P
Vol.11 No.3 (2025)

Evaluation of the Some Mechanical and Surface Properties of Denture Base Materials Fabricated by 3D-Printer when Provided of ZrO_2 and TiO_2 Nanoparticles: Systematic Review in Vitro Studies

Ali Ramadhan Ibrahim* and Yousif Jabbar Al-Timime
College of Dentistry/ AL-Kunooze University
***Corresponding author: ali.ramadhan@kunoozu.edu.iq**
Received: 15-3-2025 Accepted: 12-4-2025

Abstract

Integrate dentistry and informatics have emerged in the emergence of a new technology like 3d printing.

The objective of the study was to evolve the effectiveness of nanoparticles on some important mechanical properties for the base of denture which is made by 3d printing. The procedure of work was first collected and analyzed, and relevant articles were chosen, the general databases were searched for articles published that appeared between 2010 and 2024, and we grouped relevant search terms, such as 3D-printer denture base, nanoparticles, mechanical test This review was develop using the literature search was performed with PubMed/MEDLINE, Web of Science and EMBASE databases, until 30 June 2024.

Printing resin presented the values of the flexural strength, tensile, and impact strength were improved by addition with a limited concentration of ZrO_2 and TiO_2 compared between them while indirect tensile and hardness appeared different results. The roughness does not appear any different value.

Keywords: Three-dimensional print, Flexural strength, hardness

Introduction

The emergence of (3-Dimensional) printing in dentistry has afforded the practitioner capabilities that have recently been limited to laboratories. Over the last few years, 3D printing technology has given clinicians more attainable more accurate, cost-effective, and time-efficient. The 3D printing is the data acquired from intraoral optical scanners. This data is then converted into standard tessellation, where it can be uploaded to 3D modeling software to be manipulated. Clinicians upload the files onto a printer of choice. In dentistry, stereolithography and digital light processing are called additive manufacturing techniques. The capabilities to produce various material types such as ceramic and acrylic resin, and post-manufacturing procedures are conducted to ensure the product is free of imperfections and properly cured [1]. Partial or complete dentures, crowns, bridges, or even implant-retained prostheses are used by a significant number of people around the world who have lost their teeth. The prevalence of edentulism and the loss of all-natural teeth significantly differ in different countries. In the United States, recent research by Slade et al.[2] Preserving treated teeth, supporting the tissues, maintaining an esthetic appearance, and providing mechanical fracture against mastication forces are essential components of interim prostheses. [3]The PMMA and its copolymers are most popular in the case of non-metallic materials. m. by Wright in 1937 Methyl methacrylate was evaluated in the clinic to find many requirements of a perfect Denture Base material [4]. Nano-metals, such as TiO_2 particles good features as nontoxicity, chemically passive, good cost, antibacterial, resistant to corrosion, and high microhardness. Furthermore, new optical, and physio-chemical properties. This is the reason give a new class of materials [5]. Studies have shown that the addition of ZrO_2 nanoparticles to resin gives good properties[6]. the world moving towards digitalization, recent improvements in science and technology have digital techniques for denture production [7]. some years ago, digital technologies were widely used in dentistry in reduced time [8] .The addition of zirconia nanoparticles and silica to the liquid resin was found to enhance wear resistance [9]. Accordingly, the aims of this systematic review were number one compare the mechanical properties of ZrO_2 nanoparticles with TiO_2 nanoparticles that were added in printing resin in the fabricated bases, and number two is consolidate the required results on the issue to give important scientific evidence to adjust the usage of accessible resources to the most appropriate clinical scenarios.

Materials and Methods

Information and search sources

Google Scholar, PubMed, Science Direct, and library electronic databases were searched for the influences of nanoparticles on the mechanical properties of dentures made by 3D printed materials with printers. The criteria for inclusion were articles collected between 2010 and 2024. This review summarized the categorization and characteristics of these technologies that were utilized in dentistry.

The investigation question was: Are the mechanical properties improved by adding ZrO_2 and TiO_2 nanoparticles to PMMA 3D printed denture base resin manufactured denture base by additive techniques? To answer these questions the inclusion criteria comprised experimental and observational studies, comparative studies between nanoparticles, and studies of mechanical properties Articles not meeting these criteria.

The search combined different terms: polymethylmethacrylate additive manufacturing and printed resin, mechanical properties, nanoparticles, TiO_2, and ZrO_2

Selection of Studies

Many steps to select the articles. Started by evaluating the titles of articles depended on the inclusion criteria

Data extrusion

To obtain the information from each article, start first by band names and manufacture size, (2) specimen dimension, (3) mechanical test, (4) parameters of printing (5) study aims and outcomes.

Results

The electronic articles search result was (68). Titles irrelevant to the research question and duplicate titles were excluded after screening the title and information of articles. Ultimately, eight studies were contained for data extraction and analysis Table 1 - 3.

Present a summary of the extracted data.

Table (1). This table represents the forms, sample dimensions, test types, and concentration with types of nanoparticles added to liquid resin

No.	NPs	Samples measurement	Mechanical tests	Centration of NPs
1	TiO_2	Disc shape 2*5mm Bar shape 3.3*10*64mm	Flexural strength Harness Impact strength	0.10,0.25,0.50 and 0.75%wt. [8]
2	ZrO_2	Disc shape 2*15 mm	Surface roughness	0.5,1,3 and 5 %wt.[27]
3	ZrO_2	Disc shape2*15mm Bar 3.3*10*64mm Bar 4*6*50 with V-notch 1.2mm	Flexural strength Hardness Impact strength Roughness	0.5,1,3 and 5 %wt. [16]
4	TiO_2	Bar 3.3*10*64mm Bar2*15mm	Flexural strength Hardness	1% and 2% wt. [15]
5	ZrO_2	Cylindrical thick 8mm*dimeter 16mm	Diametral Compressive test	2% and 3% wt. [24]
6	TiO_2	Bar 3.3*10*64mm	Flexural strength Flexural modulus	1% and2 %wt. [28]
7	ZrO_2	Cylindrical Thick 8mm* diametrical 16 mm	Diametrical Compressive strength Tensile strength	2% wt. [23]
8	ZrO2	Cylindrical Thick 8mm* diametrical 16 mm	Tensile strength	1, 2, 3, and 4% wt. [25]

The table (2) demonstrates the type of printing technique with thickness layer, utilized alcohol, and the post-curing time

N0.	Printing parameter Thick ness layer-direction of print and printing techniques	Washing process and type of alcohol	Post curing
1	50 micrometer- vertical- SLA-405	99.8% ethanol for five minutes	60C° [8]
2	50 micrometer- vertical- DLP-405	99.9 isopropyl	10 Minutes [27]
3	50 micrometer- vertical- DLP-405	99.9 isopropyl	20 Minutes for ASIGA [16] 10Minutes for NEXTDENT
4	50 Micrometer -Vertical -DLP ASIGA and SLA NEXTDENT	99.9 Isopropyl	15,60 and 90 minutes in 60C° for both materials [15]
5	50 Micrometer -Vertical DLP385	isopropyl alcohol 99.9%	20 minutes [24]
6	100 Micrometer -Zero -DLP	95% ETHANOL	NP [28]
7	50 micrometer- vertical- DLP-385	99.9 isopropyl	20 Minutes [23]
8	50 micrometer- vertical- DLP-385	99.9 isopropyl	10 minutes [25]

Table (3). Represent the conclusion and aims of the research

No.	Conclusion	Aims
1	Incorporating TiO_2 NPs into a 3Dprinted denture base significantly improved mechanical properties with best outcomes in addition 0.05wt%	evaluate mechanical and physical properties of the 3Dprinter base of the denture corporating TiO2 nanoparticles. [8]
2	ZrO2 in low-value does not affect the roughness test	Investigate the antibiofilm activity and surface roughness with the addition of ZrO_2 [27]
3	ZrO_2improved the properties of 3D-printed resins	Investigate the effect of ZrO_2 on the mechanical property of 3D printing materials[16]
4	Flexural strength increases by addition The hardness decreases by addition	Evolution of some mechanical properties. [15]
5	addition of ZrO_2 NPs not improve the material behavior as 1%wt	evaluation of resin which is utilized to 3D printing of dentures with the addition of ZrO_2 NPs on diametral strength test. [24]
6	The addition of 1% of TiO_2 is effective by enhancing both mechanical	Develop an applicable and convenient protocol for resin used in 3D printing by the addition of nanoparticles. [28]
7	The enhancement of one but the other does not enhance	Investigate the relation between the tensile to the diametrical strength after the addition of ZrO_2 nanoparticles. [23]
8	1% of ZrO2 NPs concentration among 2, 3 and 4% improved the tensile test of 3D materials	ZrO2 nanoparticles were added to improve the mechanical test. [25]

Study Methods

All the studies analyzed were in vitro investigations. Regarding the objective all the studies same purpose which is the evolution of the effect of nanoparticles Sio_2 and Zro_2 on the mechanical properties of 3D-printed denture base resin.

Mechanical Strength

Four articles evaluated the flexural strength and found the highest value to almost concentration addition than the control group (zero nanoparticles), and two studies evaluated impact, tensile, and diametrical compressive strength which found the addition of nanoparticles to materials improved the properties except diametrical compressive was less value than pure resin

Surface Properties

Three studies under analysis evaluated the hardness and most recorded different values than the control group (zero nanoparticles) one study increased while the second in different and the last study lower than the control group, while the roughness surface one study found no difference in value and other not effect in low concentration.

Discussion

Modern materials, including 3D printing resins, have been made possible by the advent of recent dental technologies. Thus, examining their overall performance especially their mechanical and physical attributes as well as their long-term performance is crucial and pertinent[10]. Due to the benefits of 3D printing materials, including accuracy with detailed models, time savings, and cost-effectiveness, the 3D printing dental business is growing. There are numerous disadvantages in terms of mechanical qualities despite these benefits. When creating dental restorations to endure stresses in the mouth cavity during chewing, it is crucial to take all factors into account [11]. One way to enhance the mechanical and physical properties of resin-based materials is to incorporate nanofillers such as metals, fibers, and oxides to create materials with better properties. Most recent efforts have concentrated on raising the filler content and, as a result, the mechanical properties. Conversely, several adverse effects have been reported, such as reduced biocompatibility, the development of air gaps that result in porosity, and the aggregation of NPs that may cause regions of stress concentration that ultimately start the propagation of cracks and cause fracture[12]. The production of prosthetics for additive dentistry involves the development of polymers. A number of variables, such as printing orientation, insufficient post-curing time, and additives that can make printable resins more viscous, might influence how the resin material behaves. In addition to poor printability, these can lead to issues like clogging, uneven flow, and decreased accuracy. Furthermore, these fillers have the potential to settle over time, increasing the thickness of the resin and causing inhomogeneity. As a result, printed products may have poor mechanical qualities. For the monomer coating to be applied to the polymerized layer during printing. Filler type, size, and concentration must be carefully studied to avoid these problems and obtain the greatest printability and material quality in printable resins [13] .Flexural, impact, and hardness are the mechanical tests of dental materials that have been studied thoroughly. Flexural strength is very important to resistance the fracture and predicts materials, so if the test reading high value relevant for reducing the number of fractures in a prosthetic base [14]. Eight studies evaluated the mechanical properties and surface properties, and after comparing the values obtained between the control group (no addition of any NPs and the other group with different concentrations from ZrO_2 and TiO_2 NPs it was greater than pure resin in four studies.[8, 15]. Concentration important factor that leads to improvement in the flexural strength and additionally homogenous distribution in a matrix of resin.[16,17] ZrO_2NPs fill the inter-polymeric spaces, lead polymer to be more resistant to crack development, and give a good distribution [11]. TiO_2 nanoparticles may interact with polymer chains in the form of a hydrogen bond. This leads to thermal stability to avoid the agglomeration of the filler materials which could lead to a hybrid composite with a weak performance [18]. the denture base should have materials incorporated into it that increase impact strength[19]. Two studies evaluated the impact strength after the addition of ZrO_2 and TO2 which increased the values of pure resin. Impact strength showed a similar behavior to flexural strength, This improvement could be due to the fine size [20] Hardness is a surface test that evaluates material resistance to deformation by abrasive factor. Thus, an acrylic's hardness indicates the matrix's degradation risk. Therefore, when hardness is unacceptable, the amount of microbial adhesion and pigmentation becomes more [21]. Three studies evaluated the hardness differences in outcomes, Altarazi et al 2023 found the addition of TiO_2 to 3Dprinted material improved the hardness due to an increase in the material viscosity led to a change in the polymerization stages of the structure matrix by reducing the activity of the unreacted monomers. This may affect monomers when converted into polymers during the polymerization process[22]. In contrast, Ali Alshake et al 2022, observed a decrease in hardness values [16]. While Maram A. AlGhamdi et al 2023 used the TiO_2 NPs on two types of 3D printed materials ASIGA and Next Dent on of this material give the same values while ASIGA material gives values lower than pure resin due to incomplete polymerization and found TiO_2 which effect on concentration. Al-Sammraaie et al evaluated the tensile and diametrical compressive strength in three studies by the addition of ZrO_2 NPs at different concentrations, the materials used in these studies showed different behavior during a test by varying rates of force, and the tensile test gave higher values than pure resin by forming a more compact with dense structure and internally fill the matrix while indirect tensile in sometimes lower than pure resin due to effect the different concentration .The 3D resin was poured into a dark bottle. mixing process was performed for the pure resin by using a mixer at room temperature before adding the NPs. Then, the NPs were added to the digits electrical scale, and mixed well with an amagnetic stirrer to make the material less viscous [23-25] To obtain a surface more comfortable should be polishing outer surface of structures [26] Abdulrahman Khattaret al 2022 and Ali A. Alshaikh et al 2022, both studies employed ZrO2 to evaluate the roughness the first study observed the roughness in low concentrations not different but when increased concentration led to improve roughness [27].while the other study showed same values between modified and unmodified resin which is attributed to different in printing information [16].

Conclusion

In conclusion, the three-dimensional printed resin appeared to behave differently, although the addition of nanoparticles enhanced the mechanical properties with variable concentrations of ZrO2 and TiO2 Nanoparticles, observing the flexural strength gave significant improvement, while impact and tensile strength appeared to similar improvement to flexural strength which used same parameters of printing from thickness layer, time of post-curing and different concentration. The hardness appears unstable behavior once increases another study decreases to the control group with the same concentration at last the roughness report gives a lower value when addition nanoparticles

Conflict of Interest: Authors declare there is no conflict of interest.

References

1. Turkyilmaz, I. and Wilkins, G.N. 3D printing in dentistry–Exploring the new horizons. Journal of Dental Sciences2021; 16(3), pp.1037-1038.

2. G. Slade, A. Akinkugbe, A.J.J.o.d.r. Sanders, Projections of US edentulism prevalence following 5 decades of decline, Journal of Dental Research, 2014;93(10) (2014) 959-965.

3. M. Topouzi, E. Kontonasaki, D. Bikiaris, L. Papadopoulou, K.M. Paraskevopoulos, P.J.J.o.t.m.b.o.b.m. Koidis, Reinforcement of a PMMA resin for interim fixed prostheses with silica nanoparticles, Journal of the mechanical behavior of biomedical materials, 2017;.69 (2017) 213-222.

4. M. Sheejith, C. Swapna, S.N.J.I.J.D.M.S. George Roshy, Evolution of denture base material: From past to new era, IOSR Journal of Dental and Medical Sciences 2018; 17(11) (2018) 23-7.

5. M.A. Ahmed, M. El-Shennawy, Y.M. Althomali, A.A.J.W.J.o. N.S. Omar, Engineering, Effect of titanium dioxide nanoparticles incorporation on mechanical and physical properties on two different types of acrylic resin denture base, World Journal of Nano Science and Engineering 2016; 6(3) (2016) 111-119.

6. M.M. Gad ,A. Rahoma, R. Abualsaud, A.M. Al-Thobity, S. Akhtar, I.A. Siddiqui, F.A.J.J.o.C. Al-Harbi, E. Dentistry, Influence of artificial aging and ZrO2 nanoparticle-reinforced repair resin on the

denture repair strength, journal of clinical and experimental of dentistry 2020;12(4)e354.

7. V. Prpić, Z. Schauperl, A. Ćatić, N. Dulčić, S.J.J.o.p. Čimić, Comparison of mechanical properties of 3D-printed, CAD/CAM, and conventional denture base materials, Journal of prosthodontics 2020;29(6) 524-528.

8. A. Altarazi, J. Haider, A. Alhotan, N. Silikas, H.J.D.M. Devlin, 3D printed denture base material: The effect of incorporating TiO2 nanoparticles and artificial aging on the physical and mechanical properties, 39(12) dental material 2023; 1122-1136.

9. A. Alshamrani, A. Alhotan, E. Kelly, A.J.P. Ellakwa, Mechanical and biocompatibility properties of 3D-printed dental resin reinforced with glass silica and zirconia nanoparticles: In vitro study, Polymers 2023;15(11) 2523.

10. A. Di Fiore, R. Meneghello, P. Brun, S. Rosso, A. Gattazzo, E. Stellini, B.J.J.o.p.r. Yilmaz, Comparison of the flexural and surface properties of milled, 3D-printed, and heat polymerized PMMA resins for denture bases: An in vitro study, Journal of prosthodontic research 2022; 66(3) 502-508.

11. M.M. Gad, F.A. Al-Harbi, S. Akhtar, S.M.J.J.o.P. Fouda, 3D-printable denture base resin containing SiO2 nanoparticles: An in vitro analysis of mechanical and surface properties, Journal of Prosthodontics 2022;31(9) 784-790.

12. H.J. Abdul-Baqi, I.N. Safi, A.N. Ahmad, A.A.J.J.o. I.S.o.P. Fatalla, C. Dentistry, Investigating tensile bonding and other properties of yttrium oxide nanoparticles impregnated heat-cured soft-denture lining composite in vitro, Journal of International Society of Preventive and Community Dentistry 2022;12(1) 93-99.

13. M. Iwaki, M. Kanazawa, T. Arakida, S.J.J.o.O.S. Minakuchi, Mechanical properties of a polymethyl methacrylate block for CAD/CAM dentures, Journal of Oral Science 2020;62(4) 420-422.

14. R. Abualsaud, M.M.J.J.o. I.S.o.P. Gad, C. Dentistry, Flexural Strength of CAD/CAM Denture Base Materials: Systematic Review and Meta-Analysis of: In-Vitro: Studies, Journal of International Society of Preventive and Community Dentistry 2022;.12(2) 160-170.

15. M.A. AlGhamdi, S.M. Fouda, N. Taymour, S. Akhtar, S.Q. Khan, M.S. Ali, A.M .Elakel, E.A. Nassar, M.M.J.N. Gad, Comparative evaluation of TiO2 nanoparticle addition and post-curing time on the flexural properties and hardness of additively fabricated denture base resins, nanomaterials. 13(23) (2023) 3061.

16. A.A. Alshaikh, A. Khattar, I.A. Almindil, M.H. Alsaif, S. Akhtar, S.Q. Khan, M.M.J.N. Gad, 3D-printed nanocomposite denture-base resins: effect of ZrO2 nanoparticles on the mechanical and surface properties in vitro, nanomaterials 2022;12(14) 2451.

17. T. Hada, M. Kanazawa, N. Miyamoto, H. Liu, M. Iwaki, Y. Komagamine, S.J.I.j.o.m.s. Minakuchi, Effect of different filler contents and printing directions on the mechanical properties for photopolymer resins, International Journal of Molecular Sciences 2022;23(4) 2296.

18. E.E. Totu, C.M. Cristache, E. Voicila, O. Oprea, I. Agir, O. Tavukcuoglu, A.C.J.M.P. Didilescu, On physical and chemical characteristics of Poly (methylmethacrylate) nanocomposites for dental applications. Material Plastic 2017; I, 54, 666-672.

19. H. Sasaki, I. Hamanaka, Y. Takahashi, T.J.D.M.J. Kawaguchi, Effect of long-term water immersion or thermal shock on mechanical properties of high-impact acrylic denture base resins, dental material journal 2016; 35(2) 204-209.

20. U. Mangal, J.-Y. Seo, J. Yu, J.-S. Kwon, S.-H.J.N. Choi, Incorporating aminated nanodiamonds to improve the mechanical properties of 3D-printed resin-based biomedical appliances, Nanomaterials 2020;10(5) 827.

21. C. Lourinho, H. Salgado, A. Correia, P.J.B. Fonseca, Mechanical properties of polymethyl methacrylate as denture base material: heat-polymerized vs. 3D-printed—systematic review and meta-analysis of in vitro studies biomedicine 2022;10(10) 2565.

22. S. Aati, Z. Akram, H. Ngo, A.S.J.D.M. Fawzy, Development of 3D printed resin reinforced with modified ZrO2 nanoparticles for long-term provisional dental restorations, dental material 2021;37(6) e360-e374.

23. M.F. Al-Sammraaie, A.A. Fatalla, Z.R.J.J.o.B.C.o.D. Atarchi, Assessment of the correlation between the tensile and diametrical compression strengths of 3D-printed denture base resin reinforced with ZrO2 nanoparticles, Journal of Baghdad College of Dentistry 2024 36(1) 44-53.

24. M. Fareed Al-Sammraaie, A.J.J.o.N. A Fatalla, The Effect of ZrO2 Nanoparticles Addition on Candida Adherence and Tensile Strength of 3D Printed Denture Base Resin, jornal of nano structure 2023;13(2) 544-552.

25. M. Fareed Al-Sammraaie, A.J.N.R.J. A Fatalla, The effect of ZrO2 NPs addition on denture adaptation and diametral compressive strength of 3D printed denture base resin, nanomedicine research journal 2023; 8(4) 345-355.

26. Ibrahim AR, Yaseen IN. Enhancing the impact strength of 3D-printed denture bases through post-curing: An experimental study on the effects of temperature and time. AIP Conference Proceedings 2025; Feb 10 (Vol. 3169, No. 1).

27. A. Khattar, J.A. Alghafli, M.A. Muheef, A.M. Alsalem, M.A. Al-Dubays, H.M. AlHussain, H.M. AlShoalah, S.Q. Khan, D.M. AlEraky, M.M.J.N. Gad, Antibiofilm activity of 3D-printed nanocomposite resin: Impact of ZrO2 nanoparticles, nanomaterials 2023;13(3).

28. Chen, S. G., Yang, J., Jia, Y. G., Lu, B., & Ren, L. TiO2 and PEEK reinforced 3D printing PMMA composite resin for dental denture base applications, Nanomaterials (Basel) 2019; 9: 1049.

تقييم بعض الخصائص الميكانيكية والسطحية لقاعدة طقم الأسنان المصنعة بواسطة طابعة ثلاثية الأبعاد عند أضافه جسيمات نانوية من ثاني أكسيد الزركونيوم وثاني أكسيد التيتانيوم - مراجعة منهجية للدراسات المختبرية

علي رمضان إبراهيم و يوسف جبار التميمي

جامعة الكنوز / كليه طب الاسنان

ملخص

برز دمج طب الأسنان والمعلوماتية مع ظهور تقنية جديدة كالطباعة ثلاثية الأبعاد.
هدفت الدراسة إلى تطوير فعالية الجسيمات النانوية في بعض الخصائص الميكانيكية المهمة لقاعدة طقم الأسنان المصنوع باستخدام الطباعة ثلاثية الأبعاد. تم جمع وتحليل إجراءات العمل أولاً، ثم اختيار المقالات ذات الصلة، والبحث في قواعد البيانات العامة عن المقالات المنشورة بين عامي 2010 و2024، وجمع مصطلحات البحث ذات الصلة، مثل قاعدة طقم الأسنان للطابعات ثلاثية الأبعاد، والجسيمات النانوية، والاختبارات الميكانيكية. طُوِّرت هذه المراجعة باستخدام البحث في الأدبيات، والذي أُجري باستخدام قواعد بيانات PubMed/MEDLINE و Web of ScienceوEMBASE، حتى 30 يونيو 2024.
أظهر راتنج الطباعة تحسنًا في قيم قوة الانثناء والشد ومقاومة الصدمات بإضافة تركيز محدود من ثاني أوكسيد الزركونيوم وثاني أكسيد التيتانيوم، بينما أظهرت نتائج الشد غير المباشر والصلابة اختلافًا. ولم تظهر أي قيمة مختلفة للخشونة.

الكلمات المفتاحية: الطباعة ثلاثية الأبعاد، قوة الانحناء، الصلابة