SHEAR BOND STRENGTH BETWEEN LITHIUM DISILICATE AND ZIRCONIA CORE AFTER ADDITION OF NANOPARTICLES: A COMPARATIVE STUDY

Amani Abduljabar. Altaie[1], Mohammad Munthir Abdulrazzaq[2], Emad Farhan Alkhalidi[1]*

[1]*Department of Conservative Dentistry, College of Dentistry, University of Mosul, Mosul, Iraq. emadfarhanalkhalidi@uomosul.edu.iq*
[2]*Department of Conservative Dentistry, College of Dentistry, Aliraqia University, Baghdad, Iraq.*

ABSTRACT

The objective of this study was evaluate the compressive strength of Lithium disilicate and shear bond strength with zirconia core after addition of Titanium dioxide and Silica dioxide nanoparticle to Lithium disilicate. Forty samples were divided into four groups. Each group contains (10) samples as follows: Group1 (control) lithium disilicate without the addition of nanoparticles. Group2 lithium disilicate with the addition of Titanium dioxide nanoparticles. Group 3 lithium disilicate with the addition of Silica dioxide nanoparticles and Group 4 lithium disilicate with the addition of Titanium dioxide and Silica dioxide nanoparticles. All samples were subjected to thermocycling for 2000 cycles, then evaluate shear bond strength between lithium disilicate and zirconia core using a Universal testing machine. Finally, all collected data should be statistically evaluated. Shear bond strength (SBS) test results showed a significant increase in modified lithium disilicate on zirconia cores (groups 2, 3, and 4) compared to the unmodified type (control group). The combination of Titanium dioxide and Silica dioxide (group 4) to lithium disilicate showed the highest bond strength among other groups. No statistical differences in the effect of Titanium dioxide nano-particles addition (group 2) and Silica dioxide nano-particles addition (group 3). Shear bond strength between lithium disilicate lithium disilicate and zirconia core can be improved by addition of either (5% wt/wt) of Titanium dioxide nanoparticles or (5% wt/wt) of Silica dioxide nanoparticles to lithium disilicate, but we can increase (SBS) to higher value if using combination of these two types of nanoparticles (Titanium dioxide+ Silica dioxide).

Key words: Nanoparticles, Titanium dioxide, Silica dioxide, Lithium disilicate, Zirconia core.

Introduction

Since the 1980s, ceramic veneer has been the most dependable, long-lasting, and recommended restorative material for anterior teeth, particularly with the ongoing advancement of adhesive procedures [1, 2]. Historically, tetragonal zirconia crystals have been the primary raw material used to make dental zirconia, with a small amount of yttria stabilizer (3Y-TZP). This kind has a low translucency yet is incredibly powerful. To do this, partially stabilized zirconia with a higher yttria concentration—4 mol% (4Y-PSZ) or 5 mol% (5Y-PSZ) was created. Zirconia's stress-induced toughening is lessened by the c-phase, which lessens its toughness and strength [3, 4]. Since its introduction as a restorative core material, zirconia has significantly increased the use of ceramic restorations in dentistry. The most often used core material is zirconia because of its remarkable mechanical properties, great strength, and eye-catching color. Since zirconia lacks the appearance of natural teeth, porcelain lithium disilicate is required to give it a more appealing appearance [5, 6]. Furthermore, the most popular method now in use for creating monolithic zirconia dental prosthesis is apparently computer-aided design and manufacturing (CAD/CAM), which is quick, simple, and time-efficient [7, 8].

Clinical studies on zirconia-based all-ceramic restorations have produced high survival rates and favorable results [9-16]. Nevertheless, the most frequent issues with these restorations are chipping, cracking, and delamination of the porcelain lithium disilicate [17-19]. It must be possible to transfer functional stresses from the porcelain lithium disilicate to the overall structure with a strong enough bond between the fundamental system and the porcelain lithium disilicate [20]. In aesthetic dentistry, porcelain is used to make cosmetic restorations that provide the desired optical transparency. Nonetheless, porcelain needs to fulfill more criteria than just aesthetic ones; it must also be durable and robust enough to support the functions of mastication [18, 19, 21]. The utilisation of lithium disilicate (LD) glass ceramics in dentistry is on the rise, and its unique mechanical and aesthetic properties make its synthesis and manufacture extremely important characteristics, as well as the difficulty of making it [22, 23]. Both the right tooth color and materials with mechanical qualities are crucial because of the forces operating on dental restorations [24].

Nanotechnology has been applied to dentistry in a number of ways, particularly for material improvement [25, 26]. The small size and high specific surface area of nanoparticles (0.1–100 nm) contribute to their special qualities as excellent mechanical, chemical, optical, and magnetic characteristics in contrast to their bulk counterparts [27, 28], including silica which has traditionally been used in

dentistry due to its color, shine, and durability. Research is now being done on a silica-based nanomaterial to enhance these intrinsic qualities [29, 30]. As a novel material for dental lithium disilicates, titanium nanoparticles (Ti-NPs), a substance with appropriate mechanical qualities, are combined with lithium disilicate synthesis to create dental ceramics that have greater strength [24, 31, 32]. Titanium dioxide possesses antimicrobial properties, is chemically inert, non-toxic, and resistant to corrosion [33], and it has outstanding photocatalytic properties and is an incredibly stable particle. The output oxidative stress is caused by reactive oxygen species [34-36].

They have demonstrated that even at low concentrations of Titanium dioxide nanoparticles, new physicochemical, electrical, and optical characteristics can be induced, leading to an enhanced new class of nanocomposite materials with high hardness. We have not yet examined how nanoparticles affect the strength of the binding to the underlying zirconia core. Thus, the purpose of the current study was to assess how lithium disilicate treated with silica and titanium nanoparticles would affect the strength of the bond at the lithium disilicate-zirconia contact, so the null hypothesis is that the addition of Silica dioxide and Titanium dioxide nanoparticles to lithium disilicate does not affect the shear bond strength of lithium disilicate veneer to the zirconia core.

Materials and Methods

Samples preparation for shear bonding strength test
Cylindrical shape zirconia cores were made by a CAD/CAM system with (9 mm × 4 mm × 4 mm) dimensions. After zirconia core construction, the surface of the lithium disilicate was roughened by a (50 μm Al_2O_3) sandblast procedure and then cleaned with ultra-sonic device [37]. Addition of silica nano-particles to lithium disilicate at a ratio of (5% by weight) [38]. The incorporation of titanium nano-particles in lithium disilicate at a ratio of 5% by weight by using a delicate electrical balance (with 0.000 digits). These concentrations of silica and titanium nano-particles were selected according to the references **(Table 1)** [35, 38].

Table 1. Materials used in this study

Materials	Composition	Manufacture	Expire date
Silica dioxide nano-particles	-Silica dioxide purity > 98%. -Size 60-70 nm. -White color.	Houston, TX, USA.	02 /06 /2026
Titanium dioxide nano-particles	-Titanium dioxide purity 99.5% -Size 40 nm. -White color.	Houston, TX, USA.	02 /06 /2026
Lithium disilicate	LiSi Dentin D-A3 Porcelain ceramic.	GC, America.	20 /06 /2033
Zirconia	(5) Yttria tetragonal zirconia polycrystalline high translucent.	VITA Zahnfabrik, Germany.	05 /01 /2025

Study grouping
At first, we determined the number of samples in each group by using G*Power (3.1.9.2) software according to previous studies [39], so the total number of samples was 40, divided into four groups (each group containing 10 samples) according to the type of nano-particles added to the lithium disilicate material as follows:

- Group 1: Lithium disilicate without any type of nanoparticle addition, over a zirconia core.
- Group 2: Lithium disilicate with (5% wt/wt) Titanium nanoparticles addition over zirconia core.
- Group 3: Lithium disilicate with (5% wt/wt) Silica nanoparticles addition over zirconia core.
- Group 4: Lithium disilicate with mixed addition of (2.5% wt/wt) of Titanium nanoparticles and (2.5% wt/wt) of Silica nanoparticles over zirconia core.

All samples were collected and measured for shear bond strength by the universal testing machine with a speed of cross head (0.5 mm/min), the blade of the testing machine should be set as close as possible to the interface of porcelain-zirconia **(Figure 1)**. The force at which zirconia-emax bond failure was calculated by dividing the failure force (Newton) by the bonded surface area (mm^2).
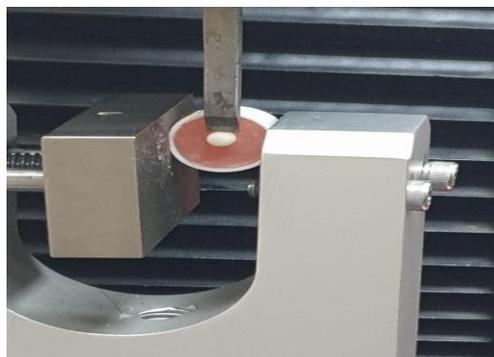

Figure 1. Represented the Universal testing machine and the sample under the blade of this machine to measure shear bond strength.

Nano-particles mixed with lithium disilicate lithium disilicate powder in a correct ratio by loading these two materials for each sample into empty and clean capsule of amalgam and then mixing by using amalgamator for (2 minutes), and then this powder of lithium disilicate and nano-particles mixed with lithium disilicate molding liquid to form a past, by using moistened brush we would apply each layer of lithium disilicate paste on zirconia core as lithium disilicate with (3mm × 4mm× 4mm) dimensions until it reached the selected height, which was measured by digital caliper [40, 41]. In order to dry the samples, the furnace's open entry was heated gradually. This process is

used to remove extra water. Steam can emerge as a result. After drying off the compact. The makers' instructions were followed when firing each sample in a porcelain furnace.

After completing all samples, the zirconia core of each sample should be inserted vertically in acrylic resin, and put in a plastic PVC tube until the zirconia-emax interface, which should be placed at the same plane as the shear test blade for the universal testing machine.

Statistical analysis
With SPSS ver. 11.5.0 (SPSS Inc., Chicago, IL, USA), the data were analyzed. After the Shapiro-Wilk test was used to analyze the data, it was discovered that symmetrically distributed. Consequently, the statistical analysis One-way analysis of variance, was used to analyze the data. Duncan's test for multiple comparisons comes next. The (P < 0.05) was designated as the statistical significance level.

Results and Discussion

The means of shear bond strength of control group and nanoparticles- modified lithium disilicate lithium disilicate **(Table 2)**. The presence of (5% wt/wt) titanium oxide nanoparticles in lithium disilicate (group 2) significantly increased the (SBS) to zirconia core (P < 0.05). The presence of (5% wt/wt) silica oxide nanoparticles in lithium disilicate lithium disilicate (group3) significantly increased the (SBS) to zirconia core (P < 0.05) in comparison to control group (group1), but the addition of two nano-materials at one time is significantly increased and have the highest (SBS) to zirconia core (P < 0.05). All data collected were normally distributed, and it was parametric data.

Table 2. The means of Shear bond strengths (MPa) of nanoparticles-containing lithium disilicate to zirconia core.

GROUPS	Sample (n)	MEANS
Group 1 (Control)	10	112.8402
Group 2 (Titanium dioxide nano.)	10	292.4000
Group 3 (Silica dioxide nano.)	10	294.8000
Group 4 (Titanium dioxide+Silica dioxide)	10	483.0000

One-way ANOVA (The analysis of variance) was done to show if there is a significant difference between the groups **(Table 3)**. In results of One-Way Anova test observed significance differences between all groups at (p < 0.05), but in **Table 4** which represent Duncan's multiple range test results showed that group2 (which is Titanium dioxide modified LDGC) and group3 (which is Silica dioxide modified LDGC) these two groups had no statistical difference between them, but these two groups had statistical difference from group1 (Control) and group4 (which is combine Titanium dioxide+SiSO2 modified LDGC).

Table 3. The one-way ANOVA test of (SBS) between lithium disilicate and zirconia core.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	342653.410	3	114217.803	21.452	0.0001
Within Groups	85190.708	16	5324.419		
Total	427844.118	19			

Table 4. Results of Duncan's multiple range test.

Codes	N	1	2	3
Control	10	112.8402		
TiO	10		292.4000	
SiO	10		294.8000	
TiO+SiO	10			483.0000
Sig.		1.000	.959	1.000

Numerous fields of study have incorporated nanotechnology since it offers a range of significant answers to complex scientific and medical problems and difficulties [42-51]. A single gram of powder's surface area could equal at different spherical diameters under test, and the surface Below 100 nm, the area per gram grows dramatically. In some materials, this results in a phase shift that raises the surface energy per gram of substance. There are several possible uses for this extra surface area of causes [52, 53]. The entire binding strength between dentin and biomaterials is strengthened by these nanoparticles. Studies conducted in vitro have shown that these nanoparticles slow the spread of cracks and make dental ceramics more resistant to fracture, avoiding crowns and other porcelain restorations, lithium disilicates, and bridges from cracking [54, 55].

Addition of nanoparticles with a reduced percentage, such as nano titanium and graphene-silver nanoparticle (R-GNs/Ag) nanocomposite, nano silicon dioxide (Silica dioxide), nano titanium dioxide (Titanium dioxide), nano chitosan, nano zirconium dioxide (ZrO_2), showed notable improvement in mechanical characteristics, because it leads to more surface area and energy, as well as more evenly distributed particles. Accordingly, new nanoparticles that exhibit potent antibacterial properties have grown in popularity in the dentistry field [56, 57].

Silicon oxide nanoparticles are a useful material for dental materials because of their many advantageous properties, which include increased strength and toughness, resistance to corrosion and abrasion, and excellent biological properties [54, 58].

In this study, we added different types of nanoparticle materials to lithium disilicate glass ceramic (LDGC) to

evaluate shear bond strength with zirconia core. The results of this study found there were significant differences in SBS between LDGC and zirconia core after the addition of different types of nanoparticles to LDGC, so the null hypotheses were rejected. Group 3 (which is modified LDGC with 5% of nano-silica) showed an increase in SBS when compared to control samples. The insertion of silica nanoparticles strengthened the shear bond in the modified samples, as stated by the latest studies conducted by Fattah *et al*. [54].

Adding nanoparticles improves the consistency and enhances the material's consistency [56, 60], and our results are in line with the results of Amer *et al*.'s study, who found that the addition of silica nanoparticles to porcelain lithium disilicate causes an increase in shear bond strength with zirconia core [35, 58].

Group 2 (which is modified LDGC with 5% of nano-titanium) showed significant elevation in SBS in comparison with the control group. Fragile LDGC-zirconia contact caused by weak and brittle LDGC can result in bond failure and chipping LDGC lithium disilicate [61, 62]. Consequently, higher bonding may have resulted from LDGC lithium disilicate's enhanced flexural strength due to the addition of nanoparticles, affecting the shear bond strength of LDGC lithium disilicate compared to the control group with regard to the zirconia core. During mixing, LDGC lithium disilicate may create air spaces that titanium oxide nanoparticles may fill. Additionally, the nanoparticles could clog the imperfections at the junction between lithium disilicate and zirconia and enhance the bond strength and surface adhesion [63, 64]. Group 4 (which is modified LDGC with combine 2.5% of Silica oxide and 2.5% of Titanium dioxide) was the highest SBS from control and other groups, because it has combine bond strength of silica and titanium nanoparticles together [65-74].

Conclusion

Shear bond strength between lithium disilicate lithium disilicate and zirconia core can be improved by addition of either (5% wt/wt) of Titanium dioxide nanoparticles or (5% wt/wt) of Silica dioxide nanoparticles to lithium disilicate, but we can increase (SBS) to higher value if using combination of these two types of nanoparticles (Titanium dioxide+ Silica dioxide).

Ethics statement: The research was approved and registered at the University of Mosul by the Department of Conservative Dentistry, College of Dentistry (Approval Code CoD06 on 02 Dec 2024).

References

1. Abood BA, Sulaiman AR. A different laser powers and their assistance in ceramic veneers removal: An in vitro study. Rafidain Dent J. 2023;23(1):187-200. doi:10.33899/RDENJ.2023.131324.1131
2. AlQassar SSS, Alkhayat ZI, Al Mallah MR. Bond integrity and microleakage of orthodontic bands cemented by glass ionomer cements stored in static magnetic field. J Adv Oral Res. 2024;15(2):151-7. doi:10.1177/23202068241247630
3. Alqutaibi AY, Ghulam O, Krsoum M, Binmahmoud S, Taher H, Elmalky W, et al. Revolution of current dental zirconia: A comprehensive review. Molecules. 2022;27(5):1699. doi:10.3390/molecules27051699
4. Lila Z, Krasniqi S, Gjelaj A, Veronneau J. Comparative analysis of enamel surface wear induced by two concentrations of zirconia particle toothpaste under two electric toothbrushing modalities. Georg Med News. 2025;358:50-6.
5. Nistor L, Grădinaru M, Rîcă R, Mărășescu P, Stan M, Manolea H, et al. Zirconia use in dentistry—manufacturing and properties. Curr Health Sci J. 2019;45(1):28-35. doi:10.12865/CHSJ.45.01.03
6. Al-Johani H, Haider J, Satterthwaite J, Silikas N. Lithium silicate-based glass ceramics in dentistry: A narrative review. Prosthesis. 2024;6(3):478-505. doi:10.3390/prosthesis6030034
7. Nazaryan R, Sosonna L, Iskorostenska O, Storozheva M, Fomenko Y, Heranin S, et al. Anatomical features of the ostiomeatal complex and their impact on complications in dental implantation. Georg Med News. 2025;358:163-7.
8. Tezulas E, Yildiz C, Kucuk C, Kahramanoglu E. Current status of zirconia-based all-ceramic restorations fabricated by the digital veneering technique: A comprehensive review. Int J Comput Dent. 2019;22(3):217-30.
9. Abdulgadir AEI, Elhag OEY, Abukanna AMA, Elmisbah HO, Idris HOI. Risk factors and clinical presentation of acute pulmonary embolism in Sudanese patients at Alshaab Teaching Hospital. J Med Sci Interdiscip Res. 2023;3(2):15-20. doi:10.51847/C6oaZYEM5g
10. Rehna S, Sreenivasulu M, Roby KAC. Clinical case report: Amputation resulting from dry gangrene. J Med Sci Interdiscip Res. 2023;3(2):35-8. doi:10.51847/pYWrA55NHJ
11. Singh N, Pradhan P, Giri R, Satapathy D. Ki-67 expression as a complementary marker for histopathological grading of astrocytic tumors. Arch Int J Cancer Allied Sci. 2023;3(2):5-10. doi:10.51847/u7xvxvsgKS
12. ElKenawy HA, Alsaeed MI, Najmi AA, Al Ghalbi AN, Daiwali IG, Alshuhay AH, et al. Role of computed

tomography in the staging and management of colorectal cancer: A clinical assessment. Arch Int J Cancer Allied Sci. 2023;3(1):10-5. doi:10.51847/bXYhJyLnSd

13. Sewankambo PR. Investigating clinical ethics consultation in Uganda: A case study at the Uganda Cancer Institute. Asian J Ethics Health Med. 2024;4:28-43. doi:10.51847/ULP3gIQWcE

14. Tutticci S, Marian M. Integrating environmental sustainability into clinical decision-making: A systematic review of rationale. Asian J Ethics Health Med. 2025;5:79-94. doi:10.51847/oGhDOKCuki

15. Poornachitra P, Maheswari U. Identifying non-specific symptoms in oral submucous fibrosis patients: A clinical perspective. Asian J Periodontics Orthod. 2023;3:18-24. doi:10.51847/xLpm4TfyCA

16. Al-Mubarak AM, Alkhaldi FA, Alghamdi AA, Almahmoud MA, Alghamdi FA. Awareness and clinical competency of dental students in crown lengthening procedures. Asian J Periodontics Orthod. 2024;4:42-51. doi:10.51847/r5cLVpz1UT

17. Ouni I, Saidi W, Mansour L. Monolithic zirconia as permanent solution for bruxism: two years follow-up. Al-Rafidain Dent J. 2023;23(2):220-7. doi:10.33899/rdenj.2023.141602.1214

18. Altaie AA, Alkhalidi EF. Effect of plasma treatment on tensile bond strength of 5Yttria zirconia coping fixed on titanium implant abutment. Pharmacog J. 2024;16(1).

19. Altaie AA, Alkhalidi EF. The effect of mechanical and energetic methods for surface treatments of titanium implant abutments on the tensile bond strength with (5) yttria zirconia crowns. Tikrit J Dent Sci. 2024;12(2):452-62.

20. AlKahtani RN. The implications and applications of nanotechnology in dentistry: A review. Saudi Dent J. 2018;30(2):107-16. doi:10.1016/j.sdentj.2018.01.002

21. McLaren EA, Cao PT. Ceramics in dentistry—Part I: classes of materials. Inside Dent. 2009;7(October):94-103.

22. Gracis S, Thompson VP, Ferencz JL, Silva NRFA, Bonfante EA. A new classification system for all-ceramic and ceramic-like restorative materials. Int J Prosthodont. 2015;28(3):227-35. doi:10.11607/ijp.4244

23. Kordjamshidi A, Saber-Samandari S, Ghadiri Nejad M, Khandan A. Preparation of novel porous calcium silicate scaffold loaded by celecoxib drug using freeze-drying technique: fabrication, characterization, and simulation. Ceram Int. 2019;45(11):14126-35. doi:10.1016/j.ceramint.2019.04.113

24. Khandan A, Nassireslami E, Saber-Samandari S, Arabi N. Fabrication and characterization of porous bioceramic-magnetite biocomposite for maxillofacial fractures application. Dent Hypotheses. 2020;11(3).

25. Aly AA, Zeidan ESB, Alshennawy AA, El-Masry AA, Wasel WA. Friction and wear of polymer composites filled by nanoparticles: A review. World J Nano Sci Eng. 2012;2(1):32-9. doi:10.4236/wjnse.2012.21006

26. Mohammed AJ, Al-Awadi HK, Al-Shukri HHK. Synthesis and characterization of aspartame and neotame-encapsulated PLGA-TPGS nanoparticles and their modulatory effects on acetylcholinesterase gene expression in male rats. Regul Mech Biosyst. 2025;16(2):e25067. doi:10.15421/0225067

27. Abood SH, Raoof WM, Al-Marjani MF. ZnO nanoparticles prepared by hydrothermal method and their role on gene expression of TA system type II genes in carbapenem-resistant Klebsiella pneumoniae. Pharmakeftiki. 2025;37(3):203-16. doi:10.60988/p.v37i3.248

28. Karabela MM, Sideridou ID. Synthesis and study of properties of dental resin composites with different nanosilica particle sizes. Dent Mater. 2011;27(8):825-35. doi:10.1016/j.dental.2011.04.008

29. Ha SW, Weiss D, Weitzmann MN, Beck GR. Applications of silica-based nanomaterials in dental and skeletal biology. In: Subramani K, Ahmed W, editors. Nanobiomaterials in Clinical Dentistry. 2nd ed. Elsevier; 2019. p. 77-112. doi:10.1016/B978-0-12-815886-9.00004-8

30. Yin IX, Niu JY, Xu VW, Yu OY, Zhao IS, Chu CH. Application of amorphous nanomaterials in dentistry: A comprehensive review. J Funct Biomater. 2025;17(1):11. doi:10.3390/jfb17010011

31. Fathi RG, Taqa GA. Osseointegration of titanium implants modulated by vitamin K2 and yerba mate extract in an animal model. Regul Mech Biosyst. 2025;16(1):e25034. doi:10.15421/0225034

32. Maghsoudlou MA, Nassireslami E, Saber-Samandari S, Khandan A. Bone regeneration using bio-nanocomposite tissue reinforced with bioactive nanoparticles for femoral defect applications in medicine. Avicenna J Med Biotechnol. 2020;12(2):68-76.

33. Aghbolaghi N, Maleki Dizaj S, Negahdari R, Jamei Khosroshahi AR, Rezaei Y, Bohlouli S, et al. Effect of adding silica nanoparticles on the physicochemical properties, antimicrobial action, and the hardness of dental stone type 4. Int J Dent. 2022;2022:4762017. doi:10.1155/2022/4762017

34. Yahya E, Jamel R. Nanoparticles as endodontic irrigation: An update overview. Al-Rafidain Dent J. 2023;23(1):37-52. doi:10.33899/rdenj.2023.133586.1161

35. Amer A, Mohsen C, Hashem R. Effect of nanosilica incorporation on flexural strength, shear bond strength, and color of veneering porcelain after thermocycling. Open Access Maced J Med Sci. 2022;10(D):380-8.

36. Latini V, Feliczak-Guzik A, Wawrzyńczak A. Application possibilities of sustainable nanostructured silica-based materials in cosmetics. Cosmetics. 2025;12(4):134. doi:10.3390/cosmetics12040134

37. Rezvani MB, Atai M, Hamze F, Hajrezai R. The effect of silica nanoparticles on the mechanical properties of fiber-reinforced composite resins. J Dent Res Dent Clin

Dent Prospect. 2016;10(2):112-7. doi:10.15171/joddd.2016.018

38. Hashem R, Kotb Salem S. Flexural strength, shear bond strength, and color change of veneering dental porcelain modified by silver nanoparticles on zirconia and metal cores. Egypt Dent J. 2023;69(2):1189-98. doi:10.21608/edj.2023.178519.2367

39. Rajaei A, Kazemian M, Khandan A. Investigation of the mechanical stability of lithium disilicate ceramic reinforced with titanium nanoparticles. Nanomed Res J. 2022;7(4):350-9. doi:10.22034/nmrj.2022.04.005

40. Altaie AA, Alkhalidi EF. Effect of curing technique and Emax type on the polymerization of dual-cure resin cement. Dentistry 3000. 2025;13(1):1-6. doi:10.5195/d3000.2025.939

41. Nikanjam S, Firouz F, Farmany A, Farhadian M, Shishean A, Masomian Z. The effect of adding silver nanoparticles on the color stability of feldspathic porcelains. Dent Res J. 2023;20:88.

42. Almeida J, Santos P, Neves R, Costa B. Pharmacogenomic landscape of South Korea: implications for tailored medical treatments. Spec J Pharmacogn Phytochem Biotechnol. 2023;3:116-29. doi:10.51847/39Z3o1BxGE

43. Chen WJ, Wu CL, Huang YC, Lin PC, Tsai MH. Precision medicine readiness among Malaysian community pharmacists: high perceived value, moderate knowledge, and urgent training needs. Spec J Pharmacogn Phytochem Biotechnol. 2025;5:27-38. doi:10.51847/xiZEcWNmB8

44. Kim J, Choi M, Lee S. Balancing risks and benefits: Anti-nutrient content versus methane-suppressing potential of medicinal plants in maize stover-based ruminant diet. Interdiscip Res Med Sci Spec. 2024;4(1):69-81. doi:10.51847/re9QquHfZm

45. Mwinyi J, Salum K, Rashid A. Assessment of nurses' practices in cleaning non-critical medical equipment during the COVID-19 pandemic: A cross-sectional study at Debre Tabor Comprehensive Specialized Hospital. Interdiscip Res Med Sci Spec. 2025;5(2):36-42. doi:10.51847/zVh4v5LUP2

46. Česaitis L, Jonušas R, Latakas D, Janužis G, Razukevičius D. A comprehensive review on the efficacy of amoxicillin, amoxiclav, and chlorhexidine as prophylactic measures following tooth extraction. J Curr Res Oral Surg. 2024;4:32-40. doi:10.51847/0zwmDoY3YU

47. O'Connor MT, McLean SL, Farouk AS. Pregnancy-related oral health beliefs in Southwestern Ontario: prevalence and implications for maternal and fetal health. J Curr Res Oral Surg. 2023;3:45-53. doi:10.51847/QExZ2wDFR4

48. Zhang Y, Pan A, Wang J, Pan X, Chen J, Li H, et al. Assessing the role of play therapy in easing anxiety and despair in children with cancer. Int J Soc Psychol Asp Healthc. 2023;3:40-8. doi:10.51847/S7vZ2lgmuc

49. Wempe MF, Hendricks-Ferguson VL, Thackray J, Raybin J. Examining the impact of story therapy and art-play therapy on pediatric cancer patients. Int J Soc Psychol Asp Healthc. 2023;3:49-54. doi:10.51847/EIL68I15uE

50. Wong Y, Lin S, Cheng H, Hsieh T, Hsiue T, Chung H, et al. Understanding the impact of medical humanities on internship training and performance. Ann Pharm Educ Saf Public Health Advoc. 2025;5:12-21. doi:10.51847/Z1fogzPksy

51. Silva-Hormazábal M, Alsina Á. Exploring the impact of integrated education on medical sciences: A comprehensive review. Ann Pharm Educ Saf Public Health Advoc. 2023;3:30-6. doi:10.51847/h9MdCIGsUf

52. Foong LK, Foroughi MM, Mirhosseini AF, Safaei M, Jahani S, Mostafavi M, et al. Applications of nano-materials in diverse dentistry regimes. RSC Adv. 2020;10(26):15430-60. doi:10.1039/D0RA00762E

53. Al-Thomali Y. Shear bond strength of orthodontic brackets after adding silver nanoparticles to a nano-bond adhesive at different thermal cycles and cyclic loading—an in vitro study. J Orthod Sci. 2022;11:28. doi:10.4103/jos.jos_183_21

54. Fattah Z, Jowkar Z, Rezaeian S. Microshear bond strength of nanoparticle-incorporated conventional and resin-modified glass ionomer to caries-affected dentin. Int J Dent. 2021;2021:5565556. doi:10.1155/2021/5565556

55. Khan I, Saeed K, Khan I. Nanoparticles: properties, applications, and toxicities. Arab J Chem. 2019;12(7):908-31. doi:10.1016/j.arabjc.2017.05.011

56. Pipattanachat S, Qin J, Rokaya D, Thanyasrisung P, Srimaneepong V. Biofilm inhibition and bactericidal activity of NiTi alloy coated with graphene oxide/silver nanoparticles via electrophoretic deposition. Sci Rep. 2021;11(1):14008. doi:10.1038/s41598-021-92340-7

57. Karapetyan H. The use of zirconium dioxide in dentistry and oral implantology: narrative review. Bull Stomatol Maxillofac Surg. 2025;21(2):188-99. doi:10.58240/1829006X-2025.2-188

58. Bourgi R, Doumandji Z, Cuevas-Suárez CE, Ben Ammar T, Laporte C, Kharouf N, et al. Exploring the role of nanoparticles in dental materials: A comprehensive review. Coatings. 2025;15(1):33.

59. Muyser G, Hasan RH. Translucency of nanoparticles reinforced denture base materials. Al-Rafidain Dent J. 2024;24(2):342-50. doi:10.33899/rdenj.2023.137801.1186

60. Gronwald B, Kozłowska L, Kijak K, Lietz-Kijak D, Skomro P, Gronwald K, et al. Nanoparticles in dentistry—current literature review. Coatings. 2023;13:102.

61. Komine F, Saito A, Kobayashi K, Koizuka M, Koizumi H, Matsumura H. Effect of cooling rate on shear bond strength of veneering porcelain to a zirconia ceramic material. J Oral Sci. 2010;52(4):647-52.

62. Altaie AA, Alhayaly AL, Alkhalidi EF. The plasma's promising future in biomedicine – review. Tikrit J Dent Sci. 2025;13(1):272-9.

63. Ashraf MA, Peng W, Zare Y, Rhee KY. Effects of size and aggregation/agglomeration of nanoparticles on the interfacial/interphase properties and tensile strength of polymer nanocomposites. Nanoscale Res Lett. 2018;13:214. doi:10.1186/s11671-018-2624-0

64. Banakar M, Heidari F, Heidari M, Mousavi S, Lai M. Nanotechnology and nanoparticles in oral care products. In: Nanotechnology in Cosmeceuticals. Academic Press; 2026. p. 309-42.

65. AlMoula AH, Azeez AA, Abass KS. Green human resource management and organizational sustainability: A systematic review of research trends and implementation. Asian J Indiv Organ Behav. 2024;4:120-40. doi:10.51847/QkhH5BNZ22

66. Cachón-Rodríguez G, Blanco-González A, Prado-Román C, Del-Castillo-Feito C. Exploring employee loyalty through social capital and sustainable human resource management practices. Asian J Indiv Organ Behav. 2025;5:29-35. doi:10.51847/yb3rymytqP

67. Karimov D, Rakhimova N. The impact of socially responsible human resource management on employee innovation performance: exploring the roles of person–organization fit, work engagement, and individualism orientation. Ann Organ Cult Leadersh Extern Engagem J. 2024;5:132-46. doi:10.51847/xJBYUl9BqH

68. Yi Y. Exploring the influence of conflict management on organizational behavior transformation. Ann Organ Cult Leadersh Extern Engagem J. 2025;6:36-40. doi:10.51847/JOy6fHPlip

69. García R, Torres D, Vázquez C. Next-generation sequencing in public healthcare NSCLC management: molecular profiles, actionable alterations, and survival benefits. Asian J Curr Res Clin Cancer. 2024;4(2):62-73. doi:10.51847/D8InJqFGCK

70. Morozov A, Petrova N, Ivanov S. 18F-DCFPyL PSMA PET/CT enhances detection of occult recurrence and refines management in post-prostatectomy biochemical failure. Asian J Curr Res Clin Cancer. 2025;5(2):70-82. doi:10.51847/AVNjs4Ouwd

71. Adams S, Miller T, Carter E. Patient's opinions and expectations on the role of pharmacists in asthma management in North Macedonia. Ann Pharm Pract Pharmacother. 2024;4:82-90. doi:10.51847/q9eTHpUb0m

72. Feng L, Wei G, Lei Z. Pharmacists' contributions to the management of mental health conditions: A comprehensive review. Ann Pharm Pract Pharmacother. 2024;4:125-39. doi:10.51847/ReKLpACV6c

73. O'Donnell K, Murphy RS, Nolan B. Computational exploration of IP6K1 inhibition: ligand- and structure-based insights for obesity-related therapeutics. Pharm Sci Drug Des. 2023;3:329-46. doi:10.51847/xYqaC4o5uP

74. Romero I, Campos M. Initial investigation into the therapeutic effects and pharmacological mechanisms of modified Danggui-Shaoyao San for managing depression in chronic kidney disease patients. Pharm Sci Drug Des. 2025;5:20-32. doi:10.51847/24JvICiLe0