Jurnal Kejuruteraan 37(1) 2025: 233-240
https://doi.org/10.17576/jkukm-2025-37(1)-15

Design and Development of a Novel Nano-hybrid Dental Composite: Antibacterial Silica Nanocomposite for Dental Use

Nida Asif[a,b], Ma Kun[c], Jahanzeb Sheikh[c,h], Eden Haseeb[a,d], Rabia Aziz[a,e], Ali Dad Chandio[a,f], Rashid Khan[g], Tan Tian Swee[c], Madeeha Sadia[a,c*]& Syafiqah Saidin[c]

[a]*Department of Biomedical Engineering, NED University of Engineering and Technology, Karachi, Pakistan*

[b]*Politecnico Di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano MI, Italy*

[c]*Department of Biomedical Engineering and Health Sciences, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

[d]*University of Kent, Giles Ln, Canterbury CT2 7NZ, UK.*

[e]*University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano SA, Italy.*

[f]*University of Manchester, Oxford Rd, Manchester M13 9PL, United Kingdom.*

[g] *Department of Mechanical Engineering, Faculty of Engineering, Al Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudia Arabia*

[h] *Department of Biomedical Engineering, Sir Syed University of Engineering and Technology, Karachi, Pakistan*

**Corresponding author: madeehaoz@cloud.neduet.edu.pk*

Received 12 September 2024, Received in revised form 23 October 2024
Accepted 23 November 2024, Available online 30 January 2025

ABSTRACT

Resin based dental composites is one of the promising dental materials that serves as an alternative to metal and amalgam restorations, as they resemble natural tooth and widely used in restorative dental treatments such as tooth decay and oral lesions. Despite several ongoing researches and innovations, the primary challenges associated with composite restorations are their limited durability, sensitivity, shrinkage and leakage. This research aimed to address these challenges and develop an innovative dental composite resulting in a minimal discomfort to the patient and improve long term therapeutic effi cacy. To overcome these challenges silica Nano- particles, with antibacterial agent was incorporated. Nano- particles of silica acted as filler, which was extracted from a bio-waste (rice husk). The addition of anti-microbial agents helped to minimize leakage due to shrinkage as these materials have small particle size, off ering a wide range of biological, chemical and mechanical properties. This was followed by characterization techniques which includes; SEM, XRD, FTIR and particle characterization that were evaluated and compared. The peaks of Silicon dioxide in XRD was recorded at 21.67, 38.38 and 44.68. Extracted silica particle size 47. 66 µm was further reduced to Nano size with an average size of 200 nm. FTIR spectrum showed the relative transmittance at 1000- 1090 cm^{-1}. The results met the standard measures and was much cheaper than currently used in dental industry. In future, comparative analysis testing including compressive or tensile strength and anti- bacterial testing can be performed that may further prove its potential and can be followed by clinical trials also.

Keywords: Silica nanoparticles; anti-bacterial agent; shrinkage; biocompatibility

INTRODUCTION

Globally, oral disorders have a detrimental effect on human's health, quality of life and well-being. Also, connection between underlying bacterial growth and inflammation can result in adverse effects like heart diseases, diabetes and other respiratory disorders (Sheikh et al. 2024; Goswami et al. 2021; Gupta et al. 2024). Although tremendous technological development related to hygiene education and practice has been carried out in the world (Sheikh et al. 2025; Sheikh et al. 2024), tooth decay affects one third of the population from all over the world of all age groups (Xu et al. 2024; Liu et al. 2023). As, the many treatments which are used to treat the patients of tooth decay are not seamless and need further improvements (Adeghe 2024). The dental composites are used in three situations; restoration of tooth structure (Ferracane, 2024; Khan 2023), contour (Altowayan 2023; Rathod et al. 2024), and to modify the shape of the structure of the restorations (Ouldyerou et al. 2023).

Currently, the dental composite which is used to treat the patients has many problems, like; high shrinkage (Topa-Skwarczyńska et al. 2023; Ni, 2023), leakage (Alsudairi 2023; Ibrahim 2023) and many other problems. Innovation is an important part of life. The new technologies are fundamentally applied with an improved version of the previous technology (Atallah 2023; Wang et al. 2023). So, in the fi eld of restorative dentistry improvements are still needed. Till date diff erent types of dental composites are used for therapeutic purposes, like the ceramic based (Li 2024; Labore et al. 2024), titanium based (Moxon 2024), calcium based (Esposti et al. 2024), silicate based (Kim 2024), and many others. All the mentioned materials have many defi ciencies like staining, discoloration, leaking, toxicity, water sorption and none of them can work smartly like that of the natural tooth, and causes discomfort and many other problems to the patient (Abd-Elaziem et al. 2024; Lehman et al. 2024). Studies reported that direct composite restorations had an increased risk of failures, leakages and need larger restorations after few months or years (Jelte W. Hofsteenge, 2023). Composite fillings are generally more expensive as compared to the traditional amalgam fillings due to its production cost (cost of materials), aesthetically pleasing and curing by UV light.

Therefore, this study focused on creating a dental composite with enhanced physical, chemical, optical, and thermal properties by utilizing silica extracted from rice husk, a bio-waste generated from rice. Rice husk is essentially free and considered as a waste product from different sectors (agriculture and food industry). The consumption of this waste product to get silica, solves the problem of disposal and waste treatment. This extracted silica is widely used in bio-applications, drug delivery, bioremediation, synthesis of construction material due to its various properties like durability, porosity, small size, biocompatibility, low density and enhance surface area (P.U. Nzereogu, 2023). Dental patients living in the areas having inadequate facilities avoids visiting hospitals in urban areas due to expensive treatment. It will have prospective impact on global oral health issues, especially in low resource setting areas as this act as cost effective and long lasting filling material.

A dental composite typically consists of three main components: the resin matrix, filler, and coupling agent (Chen, 2018). For this study, similar types of matrix resins were employed in this study, either separately or in combination: bis-phenol-A-glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), and triethylene glycol dimethacrylate (TEGDMA). Nano-silica particles were incorporated as a filler in the composite. Different dental composites utilized various fillers such as quartz, amorphous silica, glass fillers with metals, colloidal silica, ceramics, and organically modified ceramic oligomers (ORMOCERS). Coupling agents were compounds that mechanically and chemically bonded the resin matrix to the filler particles. These matrix materials were later mixed with fillers in varying weight ratios. Fillers, which were inorganic particles, provided the mechanical strength and reinforcement of the dental composite (Kundie 2018). The features that make rice husk extracted silica nanoparticles as effective filler includes its chemical stability, high thermal stability, superior mechanical strength specifically contributes to the improved tensile strength, flexural modulus and hardness (P.U. Nzereogu, 2023).

The aim of this study is to discuss the development of a dental composite that encounter all the challenges which currently used dental composites have, with improved physical, chemical, optical and thermal properties. Moreover, this study further introduced an antibacterial agent to improve the composite's antibacterial properties that would have less chances of fracture and would be successful in preventing many types of infections caused by bacteria (Sharma et al. 2023).

METHODOLOGY

METHODS AND MATERIALS

The primary materials needed to engineer this dental composite are Rice husk (bio-waste of Rice, common name is 'Oryza sativa') obtained from local rice mill, while chemicals required during the experiments were NaOH (Sodium Hydroxide) or caustic soda, concentrated H2SO4 (Sulphuric Acid), Bis-GMA (bisphenol- A- glycerol methacrylate), TEGDMA (tri-ethylene glycol dimethacrylate), Chlorhexidine or chlorhexidine gluconate (CHG) and Deionized water.

EXTRACTION OF SILICA

The methodology to prepare materials and final product carried out in a systematic way, starting from extraction of silica from Rice Husk. The process of extraction consisted of three steps; washing and burning of rice husk to turn it into ashes that is shown in figure 1a. Dried ashes were treated with alkali and finally silica was separated from sodium silicate through filtration. The initial step was washing Rice husk thoroughly with water to remove soluble impurities and dried it in oven at 150°C for one hour. Dried rice husk was then burnt in muffle furnace at 700° for 4 hours, heating continues until white ash was formed, shown in Figure 1a. Ash was grinded slightly and then completely white amorphous ash was obtained. After the formation of Rice husk ash, it was weighed, and it was found to be almost one-fourth of the mass of rice husk. Meanwhile, alkali solution (NaOH solution) was prepared by dissolving 25-gm NaOH in 200 ml of distilled water. Later, in a flask added 25-gm of ash with 175 ml of NaOH solution at room temperature and stirred with magnetic stirrer for proper dissolving. Then solution was heated at 60-80°C followed by gentle stirring (Rungrodnimitchai 2009). This results in digestion of ash in alkali solution as shown in eq. (1).

$SiO_2 + 2NaOH \quad Na_2SiO_3 + \quad H_2O$
(Ash) (Caustic Soda) (Sodium Silicate) (Water) (1)

A colorless, viscous, and transparent solution of sodium silicate was obtained after the burnt or undigested ash particles were filtered out. Figure 1b showed the separated sodium silicate solution, while Figure 1c displayed the residue left on the filter paper. This residue was the burnt portion of the rice husk ash that did not dissolve in the solution and was filtered out.

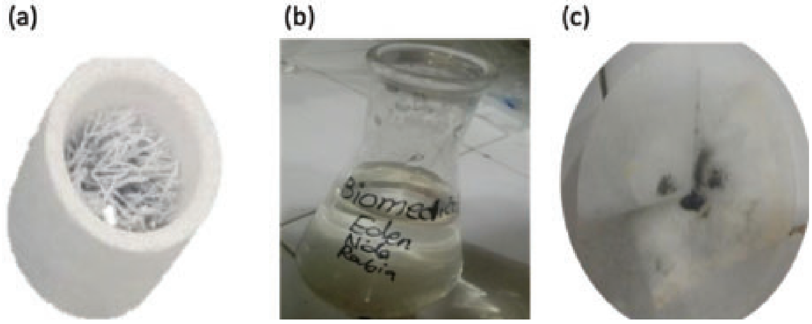

FIGURE 1. (a) White ash obtained after drying, (b) Sodium silicate solution left after filtration, (c) Residue on filter paper

The filtrate was then heated in an oven at 100-150 °C for 60 to 90 mins until the water evaporated, leaving behind a gelatinous sodium silicate. Preliminary tests, such as pH, specific gravity, and solubility, were conducted in the Materials Department laboratory to analyze the sodium silicate. Finally, the gelatinous sodium silicate was placed in a beaker, and concentrated sulfuric acid was slowly added until the solution became acidic (Katoueizadeh et al. 2020). This exothermic process resulted in the precipitation of silica, with sodium sulfate settling in the beaker as a by-product (eq. (2)).

$Na_2SiO_3 + H_2SO_4 \quad SiO_2 \quad Na_2SO_4 + H_2O$ (2)
(Sodium silicate)(Sulphuric acid) (Silica) (Sodium sulfate) (Water)

The wet, impure silica was filtered and washed multiple times with distilled water to remove any remaining sulfate. Afterward, the sample was dried in an oven to evaporate the water.

PREPARATION OF NANO-PARTICLE

Following the extraction of silica, a particle characterization test was performed. Based on the determined particle size range, a ball milling machine was selected to produce silica nanoparticles. The ball mill operates on the principle of impact and attrition. A planetary ball mill was used for 6 hours, with distilled water as the medium for wet ball milling. The sample obtained after ball milling is shown in Figure 2. Subsequently, another particle characterization test was conducted to evaluate the nanoscale particle size.

FIGURE 2. Demonstration of the sample obtained after ball milling

PREPARATION OF DENTAL COMPOSITE WITH ANTIBACTERIAL AGENT

As dental composite composed of three components, filler part, matrix and diluents. The silica Nano-particles were used as filler material for preparing improved Nano-hybrid dental composite. Bis-GMA and TEGDMA were used in different ratios (40:60 and 50:50) to prepare samples of dental composite. The filler part was then added incrementally to obtain homogenous mixture. Filler to matrix ratio in both samples varies with 40/60 and 50/50 ratio respectively. To enhance the properties of this novel dental composite, anti-bacterial agent- chlorhexidine was added in different proportions in both samples.

CHARACTERIZATION OF MATERIALS

The pure white amorphous silica was analyzed by the X-Ray Diffraction unit (Model: XRD Unit Phywe 4.0, Germany) for its molecular and chemical composition. Fourier Transform Infrared (FTIR) spectroscopy was carried out using Thermofisher FTIR (Model: NICOLET ISO50, USA) on extracted silica to analytically test the chemical and molecular properties of the sample. Before preparing silica Nano-particles, the characterization test was performed by Particle Size Analyzer (also called UV visible analyzer) (Model: LPSA BT- 9300H). Furthermore, microanalysis testing carried out after wet milling using Planetary Ball Mill (Model: TENCAN- XQM-16A, China), on silica Nano-particles by Scanning Electron Microscopy (SEM) (Model- JEOL JSM-IT-100, Germany).

RESULTS AND DISCUSSION

CHARACTERIZATION OF SILICA

SCANNING ELECTRON MICROSCOPY

Scanning Electron Microscopy (SEM) provided images of the samples by focusing and scanning their surfaces with a beam of electrons. The interaction between the electrons and the atoms of the sample generated signals that resulted in the SEM images used to analyze morphology of the sample. Figure 3 displayed the SEM results of the silica particles, showing spherical particles that were closely packed. The initial particle size of the extracted silica was 47.66 μm, which was successfully reduced to the nanoscale at an average range of 200 nm, as shown in the SEM image that was validated by the study (Rungrodnimitchai et al. 2009) in which spherical silica nano- particles were in the range of 200 to 400nm. This reduction in particle size met the established standards. Sample was in fine powder form after wet ball milling. Studies reported that silica nano-particles exhibit high mechanical strength, porosity and interfacial interaction with the matrix material that helps to increase the life span of filling (Larissa Pavanello, 2024).

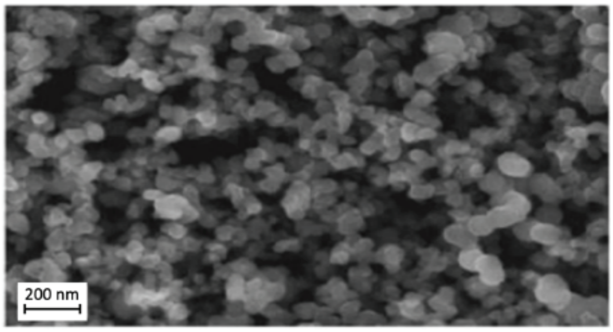

FIGURE 3. Illustrates the SEM microgram of extracted silica

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Figure 4 presented the FTIR spectra of the silica extracted from rice husk during this study. The spectrum illustrated the absorbance of infrared radiation (IR) by the sample as a function of wavelength. The Fourier transform infrared (FTIR) spectroscopy results revealed the presence of Si-O-Si stretching vibration bonds within the range of 400 to 2000 cm^{-1}. Based on these FTIR results, it was confirmed that silica was successfully extracted. The absorption peaks identified in this study, ranging from 1000 to 1090 cm^{-1}, were consistent with those reported in (Sharma et al. 2023). Study related to interpretation of FTIR used as a standard information to evaluate and compare FTIR peaks of Silica (Nandiyanto et al. 2019). That study tabled that Si-O-Si bond, under the functional group Silicon-oxy compounds should have wave numbers ranging 1095-1075 / 1055-1020, however, our results are also under the same range. Incorporation of silica nano-particles to composite fillings improve the flexural strength of overall filling material (Emad Azmy, 2022).

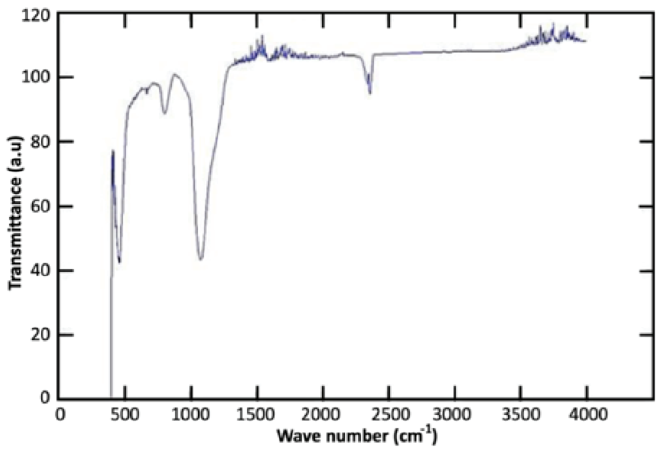

FIGURE 4. Illustrates the FTIR spectrum of extracted silica

X-RAY DIFFRACTION

The structure of the extracted silica was characterized using X-Ray Diffraction (XRD). In the initial extraction attempt, XRD analysis revealed the presence of impurities in the silica, which led to a repeat of the extraction process. After successfully extracting pure silica, another XRD test was performed to confirm the absence of impurities. Figure 5 showed the XRD diffractogram of the successfully extracted silica, with characteristic peaks of silicon dioxide recorded at 2-theta positions of 21.67, 38.38, and 44.68 degrees. To validate the XRD results, the diffractogram of the extracted silica was compared with a standard pattern (Nandiyanto, 2019), which also exhibited peaks at approximately 22, 28, and near the 40-degree range. The close alignment of these peaks with those in Figure 4 confirmed that the extracted powder was pure silica, free of impurities.

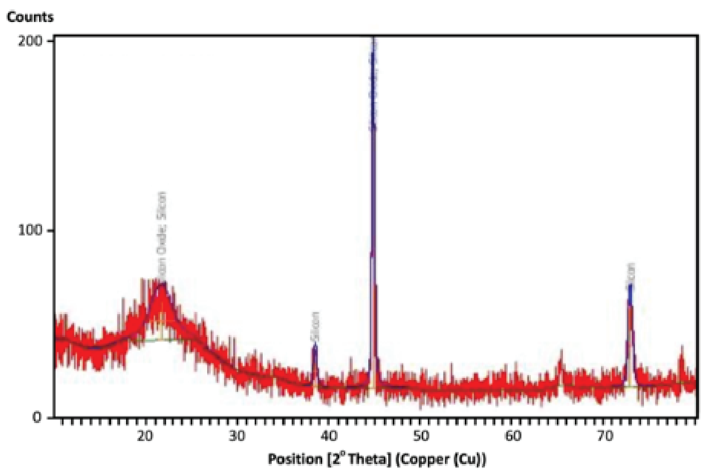

FIGURE 5. Illustrates the X-Ray diffraction pattern of extracted silica

PARTICLE CHARACTERIZATION TEST

After a successful attempt of silica extraction, a particle characterization test was performed by Particle Size Analyzer, also called UV visible analyzer. Due to variation in particle size of sample, repeated measurement of laser particle analysis was found to be effective. The principle of the testing based on laser diffraction that measures distribution of particle size by measuring scattered laser bean variation in angle. The particle size observed through this testing was 47.66 µm. As silica was in amorphous form, studies revealed that homogenous powder size in not possible to be recorded in single digit micro meters (Rasool et al. 2015), so the average particle size in this study was in correct range. Figure 6 illustrates the result in graphical form.

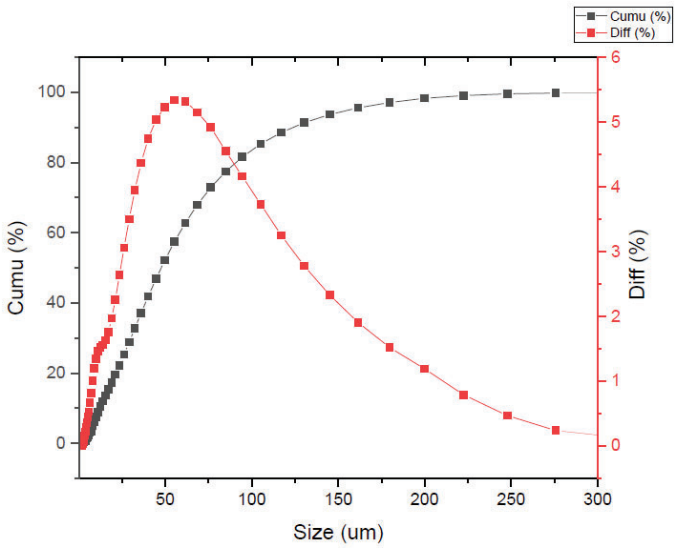

FIGURE 6. Illustrates the particle size observed through UV visible analyzer.

CONCLUSION

In light of the aforementioned results and discussions, the newly developed dental composite addresses the issues of shrinkage and leakage while making it more affordable for individuals in low-income countries. Given that a large portion of the population is affected by dental cavities, which are most aesthetically treated with dental composites, the current composites are expensive due to their import costs. The innovation of the synthesized dental composite lies in using rice husk as the primary raw material for silica extraction, which significantly reduces the cost of the composite. The nanoparticles of silica are expected to mitigate shrinkage issues, and the incorporation of chlorhexidine will provide protection against microbes that cause leakage. Peaks in XRD pattern (21.67, 38.38, and 44.68 degrees) were validated with standard results, which shows that silica was effectively extracted from rice husk using chemical treatment, and the nanoparticles were successfully produced via ball milling. FTIR spectrum of extracted amorphous Silica showed relative transmittance in range of 1000-1095 cm-1, which verifies the functional group. The silica nanoparticles serve as the main filler material, potentially extending the dental composite's lifespan compared to existing products used in Pakistan's dental industry. Additionally, by utilizing bio-waste, this approach reduces environmental contamination. As a natural and organic biomaterial is used, the environmental impact will be minimal. Ultimately, this dental composite will be more cost-effective and superior, allowing more patients to access this affordable treatment. Future testing could include anti-bacterial and animal studies to ensure safety for clinical use. This research offers a pathway for developing dental composites from organic materials, thereby reducing costs, reliance on imports, and customizing properties. Although, there are still many testing that should be done on this newly developed dental composite. In future, comparative analysis testing (including compressive strength, tensile strength and anti-bacterial response) will be carried out to compare dental composites available in market and developed by this study. Further, animal testing and human trials can also be implemented.

ACKNOWLEDGEMENT

The authors would like to acknowledge NED Alumni Association of Southern Carolina (NEDAASC) Final year project funding to support the study. The authors would also like to acknowledge Department of Biomedical Engineering NEDUET, Department of Metallurgical Engineering NEDUET, Department of Materials Engineering NEDUET and Universiti Teknologu Malaysia for their support to use Laboratories, equipment's and other resources.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Abd-Elaziem, W., Darwish, M., Hamada, A., Daoush, W. 2024. Titanium-Based alloys and composites for orthopedic implants Applications: A comprehensive review. *Materials & Design* 241: 112850.

Adeghe, E.P. 2024. Integrating pediatric oral health into primary care: A public health strategy to combat oral diseases in children across the United States. *International Journal of Multidisciplinary Research Updates* 7(1): 27-36.

Algarni A. A 2024. Antibacterial agents for composite resin restorative materials: Current knowledge and future prospects. *Cureus* 16(3): e57212.

Alsudairi, N.F. 2023. Effect of microleakage in composite filling on the health of dental pulp. *Advances in Clinical and Experimental Medicine* 10(1): 442-448

AlTowayan, S.A. 2023. Proximal contour of class II composite restoration: A literature review. *J Int Dent Med Res* 16(2): 865-872.

Atallah, W. 2023. Nanocomposites for prosthetic dental technology: A systemic review. *Journal of Techniques* 5(1): 129-136.

Azmy, E., Al-Kholy, M. R. Z., Fattouh, M., Kenawi, L. M. M., & Helal, M. A. 2022. Impact of nanoparticles additions on the strength of dental composite resin. *International Journal of Biomaterials*, *2022*, 1–9. https://doi.org/10.1155/2022/1165431

Chen, H. 2018. Dental restorative resin composites: modification technologies for the matrix/ filler interface. *Macromolecular Materials and Engineering* 303(10): 1800264.

Esposti, L., Zheng, K., Piancastelli, A., Ionescu, A., Adamiano, A., Boccaccini, A. R., Iafisco, M. 2024. Composite materials of amorphous calcium phosphate and bioactive glass nanoparticles for preventive dentistry. *Ceramics International* 50(1): 593-602.

Ferracane, J.L. 2024. A Historical Perspective on Dental Composite Restorative Materials. *Journal of Functional Biomaterials* 15(7): p. 173.

Goswami, S.K., Ranjan, P., Dutta, R.K., Verma, S.K. 2021. Management of inflammation in cardiovascular diseases. *Pharmacological research* 173: 105912.

Gupta, A., Saleena, L., Kanaan, P., Shivachandaran, A. 2024. The impact of oral diseases on respiratory health and the influence of respiratory infections on the oral microbiome. *Journal of Dentistry* 148: 105213.

Hofsteenge, J. W., Scholtanus, J. D., Özcan, M., Nolte, I. M., Cune, M. S., & Gresnigt, M. M. M. 2023. Clinical longevity of extensive direct resin composite restorations after amalgam replacement with a mean follow-up of 15 years. *Journal of Dentistry* 130: 104409. https://doi.org/10.1016/j.jdent.2023.104409

Ibrahim, H.S. 2023. Marginal leakage evaluation of bioactive bulkfill restorative materials in class II cavities: An in vitro comparative study. *Pharmacognosy Journal* 15(6): 1098-1104.

Katoueizadeh, E., Rasouli, M., Zebarjad, S.M. 2020. A comprehensive study on the gelation process of silica gels from sodium silicate. *Journal of Materials Research and Technology* 9(5): 10157–10165,

Khan, A.A. 2023. Fiber-reinforced composites in dentistry–An insight into adhesion aspects of the material and the restored tooth construct. *Dental Materials* 39(2): 141-151.

Kim, H.T. 2024. Mechanical properties, cytotoxicity, and protein adsorption of three-dimensionally printable hybrid resin containing zwitterionic polymer and silicate-based composites for dental restorations. *Journal of Dentistry* 147: 105134.

Kundie, F. 2018. Effects of filler size on the mechanical properties of polymer-filled dental composites: A review of recent developments. *Journal of Physical Science* 29(1): p. 141-165.

Laborie, M. 2024. CAD-CAM resin-ceramic material wear: A systematic review. *The Journal of Prosthetic Dentistry* 131(5): 812-818.

Lehmann, A., Nijakowski, K., Jankowski, J., Donnermeyer, D. 2024. Clinical Difficulties Related to Direct Composite Restorations: A Multinational Survey. *International Dental Journal* (In press)

Li, C., Shen, W., Wang, S., Kang, J., Zhang, Y., Wang, G. 2024. Design and 3D printing of glass-ceramic/ zirconia composite ceramics for dental application. *Ceramics International* (in press)

Liu, T., Chen, Y-C., Jeng, S-L., Cheng, J-J., Wang, J-Y., Lin, C-H., Tsai, P.F, Ko, N.Y. 2023. Short-term effects of chlorhexidine mouthwash and Listerine on oral microbiome in hospitalized patients. *Front. Cell. Infect Microbiol* 2(13): 1056534.

Moxon, R., Xu, Z., Tettey, F., Chris-Okoro, I., Kumar, D. 2024. Dental Metal Matrix Composites: The Effects of the Addition of Titanium Nanoparticle Particles on Dental Amalgam. *Materials* 17(7): 1662.

Nandiyanto, A.B., Oktiani, R., Ragadhita, R. 2019 How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology* 4(1): 97.

Ni, Z. 2023. Measuring polymerization shrinkage of dental composite by using PhS-OCT. *Measurement* 22(14): 113471.

Ouldyerou, A., Mehboob, H., Mehboob, A., Merdji, A., Aminallah, L. 2023. Biomechanical performance of resin composite on dental tissue restoration: A finite element analysis. *Plos one* 18(12): p. e0295582.

P.U. Nzereogu, Omah, A. D., Ezema, F. I., Iwuoha, E. I., & Nwanya, A. C. 2023. Silica extraction from rice husk: Comprehensive review and applications. *Hybrid Advances* 4: 100111–100111. https://doi.org/10.1016/j.hybadv.2023.100111

Patra, S., Mitra, P. and Pradhan, S.K. 2011. Preparation of nanodimensional cds by chemical dipping technique and their characterization. *Materials Research* 14(1): 17–20.

Pavanello, L., Iago Torres Cortês, Durrer, R., Zaghi, M., Cavalli, V., Tavares, L., Cidreira, C., Prokopovich, P., & Cogo-Müller, K. 2024. Physicochemical and biological properties of dental materials and formulations with silica nanoparticles: A narrative review. *Dental Materials*. https://doi.org/10.1016/j.dental.2024.07.028

Rajan, R., Zakaria, Y., Shamsuddin, S., Hassan, N.F.N. 2020. Robust synthesis of mono-dispersed spherical silica nanoparticle from rice husk for high definition latent fingermark development. *Arabian Journal of Chemistry* 13(11): 8119–8132

Rasool, T., Ahmed, S.R., Ather, I., Sadia, M., Khan, R. Jafri, A.R. 2015. Synthesis and characterization of hydroxyapatite using egg-shell. *Proceedings of the ASME International Mechanical Engineering Congress and Exposition* 3: 13–19.

Rathod. P, Patel, A., Mankar, N., Chandak, M., Ikhar, A. 2024. Enhancing Aesthetics and Functionality of the Teeth Using Injectable Composite Resin Technique. *Cureus* 16(5).

Rungrodnimitchai, S., Phokhanusai, W. & Sungkhaho, N. 2009. Preparation of silica gel from rice husk ash using microwave heating. *J Met Mater Miner* 19(2): 45-50.

Sharma,Y., Sharma, D., Waran, A., Asawa, K., Tak, M., anchariawar, S., Rawal, A. 2023. Recent advances in composite resins- an overview. *Asian J Biomed Pharmaceut Sci* 13(99): p. 175.

Sheikh, J., Swee, T.T., Saidin, S., Malik, S. 2024. Classic and alternative disinfection practices for preventing of hospital-acquired infections: a systemic review. *Int. J. Environ. Sci. Technol* 21: 8261–8296

Sheikh, J., Tan Tian Swee, Syafiqah Saidin, Yahya, A., Sameen Ahmed Malik, Chua Lee Suan, Jose Javier Serrano, Matthias, Leong Kah Meng, & Shafique, J. 2024. Comparative efficacy assessment of solitary SMD beaded ultraviolet-C light emitting diodes for enhanced disinfection of high-touch surfaces (Optimization of surface disinfection utilizing SMD beaded UV-C LEDs). *Jurnal Kejuruteraan* 36(5): 2129–2136. https://doi.org/10.17576/jkukm-2024-36(5)-30

Sheikh, J., Saidin, S., Malik, S. A., Tan, T. S., Chua, L. S., Ahmed, A. A. I. M., ... & Leong, K. M. (2024). Enhanced Irradiance Levels using Synergistically Engineered Monochromatic Wavelength Ultraviolet-C Arrays Configuration. *Journal of Human Centered Technology,* 3(1), 53-60

Sheikh, J., Tan Tian Swee, Syafiqah Saidin, Chua Lee Suan, and Sameen Ahmed Malik, 2025 Synergistic augmentation of EtOH carried out in the world and 4-Watt ultravilet-C for rapid surface decontamination, *International Journal of Biomedical Engineering and Technology 47:1, 28-43*

Topa-Skwarczyńska, M. & Joanna, O. 2023. Photopolymerization shrinkage: strategies for reduction, measurement methods and future insights. *Polymer Chemistry* 14(18): p. 2145-2158.

Wang, G., Wang, S., Dong, X., Zhang, Y., Shen, W. 2023. Recent progress in additive manufacturing of ceramic dental restorations. *Journal of Materials Research and Technology* 26:1028-1049.

Xu, L., Bai, X., Li, K., Zhang, G., Zhang, M., Hu, M., Hyuang, Y. 2024. Human exposure to ambient atmospheric microplastics in a megacity: Spatiotemporal variation and associated microorganism-related health risk. *Environmental Science & Technology* 58(8): 3702-3713