Laser Innovations for Research and Applications

journal homepage: https://lira.journals.ekb.eg/

ISSN: Print 3009-6359 / Online 3009-6472

Therapeutic Potential of Moringa oleifera and Bioactive Glass Nanoparticles for Dental Remineralization and Antimicrobial Applications: A Comprehensive Review

Howida kandil[1*], Maha Niazy[2], Inas Talaat[2], and Tarek Mohamed[1]

[1]Department of Medical Laser Applications, Laser Institute for Research and Applications, Beni-Suef University, Beni-Suef, 62511 Egypt.

[2]Operative Dentistry Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo 4434004, Egypt.

Abstract

This review critically evaluates recent advances in the use of Moringa oleifera extracts and bioactive glass nanoparticles for dental biomimetic remineralization and antimicrobial therapy, with particular emphasis on their activation by femtosecond laser light. The review details the antioxidant, anti-inflammatory, and antibacterial properties of Moringa oleifera, summarizing evidence for its effectiveness in reducing oral oxidative stress, inhibiting key cariogenic bacteria, and promoting dentin and bone remineralization due to its high calcium and phosphorus content. The synergistic effects of Moringa oleifera combined with fluoride are also discussed. For bioactive glass nanoparticles, the review outlines their chemical composition, ability to release remineralizing ions, and their application in dental composites, bone regeneration, and caries management. The impact of femtosecond laser activation on enhancing the bioactivity and antimicrobial efficacy of both agents is highlighted. By synthesizing findings from in vitro, in vivo, and clinical studies, this review identifies promising strategies for integrating natural and synthetic remineralizing agents in restorative dentistry, while also outlining current research gaps and future directions for optimizing their clinical use.

Keywords: Antimicrobial agents, Biomimetic remineralization, Dental restoration, *Moringa oleifera*.

*Corresponding author at: Laser Institute for Research and Applications LIRA, Beni-Suef University, Beni-Suef, Egypt

E-mail addresses: howida.kandil@gmail.com (H.K.)

1. Introduction

Moringa oleifera, also known as the drumstick tree or horseradish tree, has been utilized for its therapeutic properties in traditional medicine for centuries(Thapa et al., 2019). The plant finds its roots in the Indian subcontinent and has been extensively cultivated in various parts of the world due to its numerous health benefits(Thapa et al., 2019). The use of Moringa oleifera in traditional medicine can be traced back thousands of years. In Ayurvedic medicine, the plant is employed to treat various ailments such as digestive disorders, respiratory infections, skin diseases, and joint pain. The plant is also believed to possess anti-inflammatory and anti-oxidant properties(Padayachee & Baijnath, 2020). In traditional African medicine, Moringa oleifera has been used to treat a variety of conditions, including malaria, tuberculosis, and high blood pressure. Different parts of the plant, such as leaves, bark, roots, and seeds are utilized in distinct ways to treat different ailments(Biswas et al., 2020). In recent years, there has been a growing interest in the potential use of Moringa oleifera in modern medicine. Scientific studies have confirmed many of its traditional uses and identified new potential therapeutic applications. For example, studies have revealed that Moringa oleifera has anti-inflammatory, antimicrobial, and antioxidant properties and may help treat conditions such as diabetes, hypertension, and cancer. Additionally, the plant has been found to have beneficial effects on the cardiovascular system, immune system, and nervous system(Thapa et al., 2019). Overall, the historical use of Moringa oleifera in traditional medicine highlights its numerous health benefits. Nevertheless, further research is required to fully comprehend its mechanisms of action and determine its optimal dosage and mode of administration in modern medicine(Thapa et al., 2019). This review aims to critically evaluate and synthesize current research on the biomimetic remineralization and antimicrobial effects of Moringa oleifera and bioactive glass nanoparticles, with particular emphasis on their mechanisms of action, dental applications, and the potential enhancement of their properties through activation by femtosecond laser light. The review seeks to clarify the therapeutic potential, limitations, and prospects of these natural and synthetic agents in restorative dentistry.

1.1. Significance of *Moringa oleifera* in dentistry

In recent years, there has been a growing interest in the potential use of Moringa oleifera (Fig.1) in dentistry to prevent and treat oral diseases (Kou et al., 2018). One of the key components of Moringa oleifera is its high concentration of antioxidants, which have been shown to have a protective effect against oxidative stress-induced damage to the oral tissues. Singh et al. (2016) found that Moringa oleifera extract exhibited significant antioxidant activity and was effective in reducing oxidative stress in the oral cavity (Singh et al., 2016). In addition to its antioxidant properties, Moringa oleifera has also been shown to have anti-inflammatory and antibacterial effects, which make it a promising candidate for the prevention and treatment of periodontal disease. Dhakad et al. (2019) found that Moringa oleifera leaf extract exhibited significant antimicrobial activity against a range of oral bacteria, including Streptococcus mutans, which is a key pathogen in the development of dental caries (Dhakad et al., 2019). Furthermore, Moringa oleifera has been shown to have a positive effect on bone health, which is important in the context of oral and maxillofacial surgery. Siddiqui et al. (2022) found that Moringa oleifera extract was effective in promoting bone regeneration in rats with induced bone defects (Khan et al., 2022). In summary, the available literature suggests that Moringa oleifera holds promise as a natural adjunctive therapy for the prevention and treatment of various oral diseases. However, further research is needed to fully elucidate its mechanisms of action and to determine its optimal dosage and mode of administration (Padayachee & Baijnath, 2020).

Fig. 1: Optical image of Natural agent, Moringa oleifera extract

1.2. Nutritional benefits of *Moringa oleifera* in oral cavity

One of the key nutritional benefits of Moringa oleifera is its high calcium and phosphorus content, which are essential for healthy teeth and bones. Gopalakrishnan et al. (2016) found that Moringa oleifera leaf powder was effective in increasing the levels of calcium and phosphorus in the teeth and bones of rats (Gopalakrishnan et al., 2016). Moreover, the antioxidant properties of Moringa oleifera may have a protective effect on the oral tissues. Saini et al. (2016) found that Moringa oleifera extract effectively reduced oxidative stress markers in patients with periodontitis, a common oral disease (Saini et al., 2016). Additionally, the anti-inflammatory properties of Moringa oleifera may have positive effects on the oral cavity.

Thangavelu et al. (2023) found that Moringa oleifera leaf extract was effective in reducing inflammation and bone resorption in rats with induced periodontitis (Jasim et al., 2023). In summary, the available literature suggests that the high nutritional value of Moringa oleifera may have positive effects on the oral cavity. However, more research is needed to fully understand the specific nutritional benefits of Moringa oleifera in dentistry(Gopalakrishnan et al., 2016; Jasim et al., 2023; Saini et al., 2016).

1.3. *Moringa oleifera* in dentin remineralization

Moringa oleifera has been found to have potential in dentin remineralization due to its high calcium and phosphorus content, which are essential minerals for tooth mineralization. A study by Mosallam et al. (2021) demonstrated that Moringa oleifera leaf extract has the ability to enhance dentin remineralization (Farouk et al., 2021). The study found that Moringa oleifera leaf extract exhibited a significant increase in the microhardness of demineralized dentin, indicating an increase in mineral density. This result suggests that Moringa oleifera could be a promising natural agent for the remineralization of demineralized dentin. Another study by Meena et al. (2021) investigated the potential of Moringa oleifera in combination with fluoride to enhance dentin remineralization. The study found that the combination of Moringa oleifera and fluoride was more effective in remineralizing demineralized dentin compared to fluoride alone (Meena et al., 2021). Furthermore, the anti-inflammatory and antibacterial properties of Moringa oleifera may also have positive effects on dentin remineralization. A study by Sharma et al. (2021) found that Moringa oleifera leaf extract exhibited significant antibacterial activity against oral pathogens and had the potential to inhibit biofilm formation (Bhatia et al., 2021). Overall, the available literature suggests that Moringa oleifera has potential in dentin remineralization and could be a natural alternative to synthetic agents. However, further research is needed to understand its mechanisms of action fully and to determine its optimal dosage and mode of administration.

2. Bioactive glass nanoparticles
2.1. Historical medicinal uses of Bioactive glass nanoparticles

Bioactive glass nanoparticles (BGn) have been used in biomedical applications since the 1960s, and their use has been growing rapidly in recent years due to their unique properties. BGn is composed of silicon, calcium, sodium, and phosphorus, and can bond to living tissue, promoting bone growth and regeneration (Spicer et al., 2012). Fig. 2 shows Optical image of Dental Material, Bioactive glass nanoparticle sample. Early use of bioactive glass was as a bone graft substitute, but the introduction of BGn has allowed for more precise and targeted delivery of the material. BGn can be incorporated into various materials, such as polymers and ceramics, to create composites with enhanced properties. One of the key advantages of BGn is their ability to enhance bone regeneration. A study by Sloan et al. (2017) found that BGn enhanced the proliferation and differentiation of human bone marrow stromal cells, leading to increased bone formation (Avery et al., 2017). In addition to their bone regenerative properties, BGn has been shown to have antibacterial properties. A study by Kim et al. (2018) found that BGn was effective in inhibiting the growth of various bacteria, including Staphylococcus aureus and Escherichia coli (Lee et al., 2018). Furthermore, BGn have been used as drug delivery vehicles due to their high surface area and ability to be functionalized with various molecules. A study by Gosh et al. (2021) found that BGn loaded with the antibiotic vancomycin was effective in treating bone infections in rats (Ghosh & Webster, 2021). On the whole, the historical use of bioactive glass has evolved with the introduction of BGn, allowing for more precise and targeted delivery of the material. The unique properties of BGn, including their ability to enhance bone regeneration, inhibit bacterial growth, and deliver drugs, make them a promising material for biomedical applications.

Fig. 2: Optical image of Dental Material, Bioactive glass nanoparticle

2.2 Chemical composition and benefits of bioactive glass nanoparticles in dentistry

Bioactive glass nanoparticles (BGn) are composed of silicon, calcium, sodium, and phosphorus, and can bond to living tissue, promoting bone growth and regeneration (Kang et al., 2018). BGn has been used in various dental applications due to their unique properties, including their ability to stimulate mineralization and promote the growth of new bone tissue. One of the key benefits of BGn in dentistry is their use in dental composites. A study by sshatkoski et al. (2019) found that BGn could be incorporated into dental composites to improve their mechanical properties and biocompatibility. The study also found that the addition of BGn reduced the release of toxic monomers from the composite, making it safer for use in the oral cavity (Ribas et al., 2019). In addition to their use in composites, BGn has been used in dental bone regeneration. A study by Zhang et al. (2022) found that BGn was effective in promoting bone formation and regeneration in the jawbone of rabbits. The study also found that the incorporation of BGn into a collagen scaffold improved the mechanical properties of the scaffold and enhanced bone regeneration (Qin et al., 2022). Furthermore, BGn have been used in the treatment of dental caries. A study by Tyagi et al. (2022) found that BGn-based materials were effective in inhibiting the growth of Streptococcus mutans, a bacteria commonly associated with dental caries. The study also found that the BGn-based materials had better antibacterial properties than traditional dental materials (Chen et al., 2022). In conclusion, BGn have shown promise in various dental applications, including the improvement of dental composites, bone regeneration, and the treatment of dental caries. The unique properties of BGn, including their ability to stimulate mineralization and promote the growth of new bone tissue, make them a promising material for use in dentistry. Bioactive glass nanoparticles (BGn) have been explored for their potential use in various dental applications due to their unique properties, including their ability to promote bone growth and regeneration, as well as their antibacterial properties. Furthermore, BGn have been explored for their potential use in dental pulp capping, a procedure used to treat pulp inflammation and prevent the need for root canal treatment. A study by Kargozar et al. (2021) found that BGn were effective in promoting pulp cell proliferation and differentiation, as well as dentin formation, indicating their potential use in dental pulp capping (Kargozar et al., 2021). In summary, the unique properties of BGn make them a promising material for use in various dental applications, including the development of dental composites, bone regeneration, the prevention and treatment of dental caries, and dental pulp capping.

2.3. Bioactive glass nanoparticles in dentin remineralization

Dentin remineralization is an important process for the restoration of damaged or decayed teeth. Bioactive glass nanoparticles (BGn) have shown potential in enhancing this process due to their ability to release calcium and phosphate ions, which are essential for tooth mineralization (Patel et al., 2012). Several studies have investigated the efficacy of BGn in dentin remineralization. A study by Sauro et al. (2018) found that BGn-containing dentin adhesives were effective in promoting dentin remineralization and inhibiting dentin demineralization in vitro (Jun et al., 2018). Another study by Arafa et al. (2017) investigated the effect of BGn on the remineralization of dentin lesions in vivo. The study found that BGn-containing dentin adhesives were effective in promoting the remineralization of carious lesions in human teeth (Elkassas et al., 2017). In addition to promoting dentin remineralization, BGn has also been found to have antibacterial properties. A study by Cheng et al. (2020) found that BGn-containing dental composites exhibited significant antibacterial activity against Streptococcus mutans, a key pathogen in the development of dental caries (Chen et al., 2020). Furthermore, BGn has been found to have a positive effect on the mechanical properties of dentin. A study by Lee et al. (2017) found that BGn-containing dental composites exhibited improved mechanical properties, including increased hardness and reduced wear, compared to conventional dental composites (Kim et al., 2017). Overall, the available literature suggests that BGn holds promise as a natural and effective agent for dentin remineralization. However, further research is needed to understand its mechanisms of action fully and to determine its optimal dosage and mode of administration.

3. Femtosecond laser light

3.1. The history of femtosecond laser light in medicine

Femtosecond lasers (FSL) are a type of laser that emits pulses with durations in the femtosecond range (10^-15 seconds). Fig. 3 demonstrates the basic setup for exposing teeth to a laser beam. FSL have been used in a wide range of medical applications due to their ability to deliver precise and controlled energy to biological tissues, without causing thermal damage (Tang et al., 2016). The first use of FSL in medicine was reported in the early 1990s, when it was used in ophthalmology for the creation of corneal flaps in LASIK (laser-assisted in situ keratomileusis) surgery (Vestergaard, 2014). Since then, FSL has been used in various medical specialties, including neurosurgery, dermatology, and cardiology, among others (Khalkhal et al., 2019). In neurosurgery, FSL has been used for the creation of precise incisions and ablations in brain tissue, with minimal thermal damage (Xie et al., 2017). FSL has also been used in dermatology for the treatment of skin conditions, such as acne scars and wrinkles (Byun et al., 2011). Furthermore, FSL has been used in cardiology for the creation of precise incisions in heart tissue, with minimal thermal damage. This has led to the development of novel techniques for the treatment of cardiac arrhythmias, such as atrial fibrillation (Webb & Rothwell, 2016). The use of FSL in medicine has continued to evolve, with ongoing research focused on further improving their precision and efficacy, as well as exploring new applications in various medical specialties. Altogether, the history of FSL in medicine highlights the potential of this technology to revolutionize the way medical procedures are performed, by providing surgeons with a precise, safe, and effective tool for the treatment of various medical conditions.

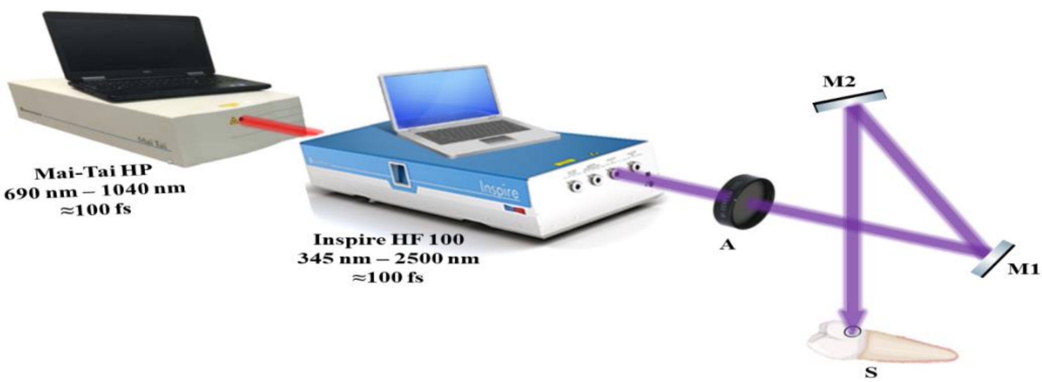

Fig. 3: The photoactivation experimental setup showing the method of sample exposure to femtosecond laser light. A, attenuator; M1 and M2, highly reflecting mirrors; S, sample.

3.2. The use of femtosecond laser light in dentistry for tissue interaction by photoactivation

Femtosecond lasers (FSL) have been used in dentistry for various applications, including cavity preparation, periodontal therapy, and endodontic treatment. FSL can interact with dental tissues by photoactivation, inducing photothermal, photochemical, and photomechanical effects (Serbin et al., 2002). One of the main advantages of FSL in dentistry is their ability to create precise and controlled cavities with minimal thermal damage, compared to conventional rotary instruments (Khalkhal et al., 2019). A study by George et al. (2023) found that FSL could create cavities with smaller surface roughness and less microcracks compared to conventional rotary instruments(Saran et al., 2023). FSL have also been used for periodontal therapy, such as in the treatment of peri-implantitis. A study by Monje et al. (2016) found that FSL could effectively remove bacterial biofilm and calculus from implant surfaces, without causing thermal damage (Khoshkam et al., 2016). Furthermore, FSL have been used in endodontic treatment for the disinfection of root canals. A study by Viana et al. (2018) found that FSL could effectively remove bacteria from root canals, with minimal thermal damage (Morton & Dover, 2014). The use of FSL in dentistry is still in its early stages, and further research is needed to fully understand their mechanisms of action and to determine their optimal dosage and mode of administration. However, the available literature suggests that FSL hold promise as a safe and effective tool for various dental applications. Overall, the use of FSL in dentistry for tissue interaction by photoactivation highlights the potential of this technology to revolutionize the way dental procedures are performed by providing dentists with a precise, safe, and effective tool for the treatment of various dental conditions.

3.3. The use of femtosecond laser light in dentin remineralization

Femtosecond lasers (FSL) have been investigated for their potential in dentin remineralization, due to their ability to create precise and controlled microstructures in dentin. FSL can be used to create microchannels and microcavities in dentin, which can enhance the penetration and delivery of remineralizing agents (Dutra-Correa et al., 2011). A study by Pecheva et al. (2018) investigated the effect of FSL on the remineralization of artificial caries lesions in dentin. The study found that FSL could enhance the remineralization of dentin lesions, with a greater increase in mineral density compared to conventional remineralizing agents (Petrov et al., 2018). The use of FSL in dentin remineralization is still in its early stages, and further research is needed to fully understand the mechanisms of action and to determine their optimal dosage and mode of administration. However, the available literature suggests that FSL holds promise as a safe and effective tool for enhancing dentin remineralization and improving the mechanical properties of dentin. Generally, the use of FSL in dentin remineralization highlights the potential of this technology to revolutionize the way dental procedures are performed by providing dentists with a precise, safe, and effective tool for the treatment of various dental conditions.

4. Laser-induced breakdown spectroscopy

4.1. The historical use of laser-induced breakdown spectroscopy (LIBS) in medicine and its mode of action

Laser-induced breakdown spectroscopy (LIBS) is a technique that uses laser pulses to vaporize a small amount of a sample, creating a plasma that emits characteristic wavelengths of light. LIBS has been used in medicine for various applications, including the analysis of biological tissues, the detection of cancerous cells, and the monitoring of drug metabolism (Anabitarte et al., 2012). The use of LIBS in medicine dates to the 1990s, when it was first used for the analysis of biological tissues (Radziemski & Cremers, 2013). Since then, LIBS has been used in various medical specialties, including dermatology, oncology, and pharmacology, among others (Kabir et al., 2022; Miziolek et al., 2006). In dermatology, LIBS has been used for the identification and characterization of skin lesions, such as melanoma and basal cell carcinoma (Han et al., 2015; Sharaha et al., 2023). In oncology, LIBS has been used for the detection of cancerous cells and for the monitoring of cancer treatment efficacy (Kumar et al., 2004). Furthermore, LIBS has been used in pharmacology for the monitoring of drug metabolism and for the identification of counterfeit drugs (Chu et al., 2020). The mode of action of LIBS in medicine involves the interaction of laser pulses with biological tissues, creating a plasma that emits characteristic wavelengths of light. The emitted spectrum can be analyzed to identify the elemental composition of the sample, providing information on the presence of disease or drug metabolism (Singh et al., 2018). The use of LIBS in medicine is still in its early stages, and further research is needed to understand its mechanisms of action fully and to determine its optimal dosage and mode of administration. However, the available literature suggests that LIBS holds promise as a safe and effective tool for various medical applications.

4.2. The use of laser-induced breakdown spectroscopy (LIBS) in dentistry

A study by Rehman et al. (2015) investigated the use of LIBS for the analysis of dental tissues, including enamel, dentin, and cementum. The study found that LIBS could accurately identify the elemental composition of dental tissues, providing information on the presence of mineral elements, such as calcium and phosphorus (Ramakrishnaiah et al., 2015). Furthermore, LIBS has been investigated for its potential in the detection of carious lesions. A study by Wagner et al. (2022) found that LIBS could accurately detect early caries lesions, with a high sensitivity and specificity, compared to conventional methods (Singh et al., 2018). The use of LIBS in dentistry is still in its early stages, and further research is needed to understand its mechanisms of action fully and to determine its optimal dosage and mode of administration. However, the available literature suggests that LIBS holds promise as a safe and effective tool for various dental applications (Hahn & Omenetto, 2010). Overall, the use of LIBS in dentistry highlights the potential of this technology to revolutionize the way dental procedures are performed, by providing dentists with a precise, safe, and effective tool for the analysis and diagnosis of various dental conditions (Noll et al., 2012).

5. Biomimetic dentin remineralization

5.1. Introduction

Dentin remineralization is a crucial aspect in the treatment of dental care. Biomimetic approaches to dentin remineralization have gained attention in recent years due to their ability to mimic natural mineralization processes.

This literature review aims to discuss the current state of biomimetic dentin remineralization and its potential as a promising alternative to conventional remineralization therapies. Biomimetic remineralization has become a widely used approach in contemporary dentistry due to its less invasive and conservative strategy. However, the effectiveness of the approach can vary depending on factors such as tissue composition, tissue response, and materials used.

5.2. Biomimetic Dentin Remineralization Process

Biomimetic approaches to dentin remineralization involve the use of biomolecules and/or bioinspired materials to mimic the natural mineralization process of dentin. One of the most common biomolecules used in this approach is casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) complex. CPP-ACP has been shown to inhibit demineralization and promote remineralization in vitro and in vivo studies (Bajaj et al., 2016). Another biomolecule, polydopamine, has also been used to promote dentin remineralization. Polydopamine-coated calcium phosphate nanoparticles have been shown to effectively remineralize artificial lesions in dentin (Qu et al., 2020).

5.3. Biomimetic dentin remineralization techniques

One of the most commonly used biomolecules in biomimetic dentin remineralization is the casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) complex. CPP-ACP has been shown to inhibit demineralization and promote remineralization in vitro and in vivo studies (Reynolds, 2008). Another biomolecule, polydopamine, has been used to promote dentin remineralization. Bioinspired materials, such as biomineralized collagen scaffolds, have also been developed for dentin remineralization. These scaffolds mimic the natural structure of collagen fibers in dentin and provide a template for mineral growth (Niu et al., 2014). Hydroxyapatite nanocrystals have also been incorporated into collagen scaffolds to enhance their remineralization potential (Besinis et al., 2014).

5.4. Clinical Applications

Biomimetic dentin remineralization techniques have shown promise in clinical applications. CPP-ACP has been incorporated into various dental products, including toothpastes, chewing gums, and mouthwashes (Meyer-Lueckel et al., 2015). Polydopamine-coated calcium phosphate nanoparticles have also been used in dental restorative materials (Cao et al., 2015). Biomineralized collagen scaffolds have been used in regenerative endodontic procedures (Li et al., 2023).

5.5. Future Directions

Despite the promising results of biomimetic dentin remineralization techniques, further research is needed to optimize these approaches and to evaluate their long-term effectiveness in clinical settings. Future studies should focus on the development of biomolecules and bioinspired materials that can effectively remineralize dentin lesions in vivo. In addition, the safety and biocompatibility of these materials should be thoroughly evaluated before they can be considered for widespread clinical use.

6. Conclusion

This review highlights Moringa oleifera, bioactive glass nanoparticles, and femtosecond lasers as promising strategies for biomimetic dentin remineralization and antimicrobial therapy. MO’s natural minerals and antibacterial properties complement BGn’s tissue-regenerative capabilities, while FSL enables precise delivery. LIBS, though not a therapeutic tool, aids in monitoring mineral content. Key limitations include insufficient clinical data and mechanistic details, particularly for laser-enhanced approaches. Future work should prioritize translational studies, standardized protocols, and comparative efficacy trials to bridge laboratory findings to clinical practice.

Funding: This research received no external funding.

Data availability: No datasets were generated or analyzed during the current study.

Conflict of interest: the authors declare no conflict of interest.

References

Anabitarte, F., Cobo, A., & Lopez-Higuera, J. M. J. I. S. R. N. (2012). Laser-induced breakdown spectroscopy: fundamentals, applications, and challenges. 2012(1), 285240.

Avery, S., Sadaghiani, L., Sloan, A. J., Waddington, R. J. J. E. C., & Materials. (2017). Analysing the bioactive makeup of demineralised dentine matrix on bone marrow mesenchymal stem cells for enhanced bone repair. 34, 1-14.

Bajaj, M., Poornima, P., Praveen, S., Nagaveni, N., Roopa, K., Neena, I., & Bharath, K. J. J. o. C. P. D. (2016). Comparison of CPP-ACP, tri-calcium phosphate and hydroxyapatite on remineralization of artificial caries like lesions on primary enamel-An in vitro study. 40(5), 404-409.

Besinis, A., Van Noort, R., & Martin, N. J. D. M. (2014). Remineralization potential of fully demineralized dentin infiltrated with silica and hydroxyapatite nanoparticles. 30(3), 249-262.

Bhatia, P., Sharma, A., George, A. J., Anvitha, D., Kumar, P., Dwivedi, V. P., & Chandra, N. S. J. H. (2021). Antibacterial activity of medicinal plants against ESKAPE: An update. 7(2).

Biswas, D., Nandy, S., Mukherjee, A., Pandey, D. K., & Dey, A. J. S. A. J. o. B. (2020). Moringa oleifera Lam. and derived phytochemicals as promising antiviral agents: A review. 129, 272-282.

Byun, H. J., Lee, H. I., Kim, B., Kim, M. N., Hong, H., Choi, Y., Jo, Y., Cho, K. H., & Mun, S. K. J. I. j. o. d. (2011). Full-spectrum light phototherapy for atopic dermatitis. 50(1), 94-101.

Cao, C. Y., Mei, M. L., Li, Q.-L., Lo, E. C. M., & Chu, C. H. J. I. j. o. m. s. (2015). Methods for biomimetic remineralization of human dentine: a systematic review. 16(3), 4615-4627.

Chen, H., Gu, L., Liao, B., Zhou, X., Cheng, L., & Ren, B. J. M. (2020). Advances of anti-caries nanomaterials. 25(21), 5047.

Chen, X., Tyagi, A., Chelliah, R., Elahi, F., Vijayalakshmi, S., Yan, P., Shan, L., & Oh, D.-H. J. P. B. (2022). Development of an eco-sustainable formulation against Streptococcus mutans and Candida albicans. 118, 103-111.

Chu, Y., Zhang, Z., He, Q., Chen, F., Sheng, Z., Zhang, D., Jin, H., Jiang, F., & Guo, L. J. J. o. A. R. (2020). Half-life determination of inorganic-organic hybrid nanomaterials in mice using laser-induced breakdown spectroscopy. 24, 353-361.

Dhakad, A. K., Ikram, M., Sharma, S., Khan, S., Pandey, V. V., & Singh, A. J. P. R. (2019). Biological, nutritional, and therapeutic significance of Moringa oleifera Lam. 33(11), 2870-2903.

Dutra-Correa, M., Nicolodelli, G., Rodrigues, J., Kurachi, C., & Bagnato, V. S. J. L. P. (2011). Femtosecond laser ablation on dental hard tissues—Analysis of ablated profile near an interface using local effective intensity. 21, 965-971.

Elkassas, D., Arafa, A. J. N. N., Biology, & Medicine. (2017). The innovative applications of therapeutic nanostructures in dentistry. 13(4), 1543-1562.

Farouk, H., Mosallam, R., & Aidaros, N. H. J. A. D. J. (2021). Effect of Green Tea, Black Tea and Moringa Oleifera on Remineralization of Artificially Demineralized Enamel and Dentin: An In-vitro Microhardness Analysis. 3(1), 24-34.

Ghosh, S., & Webster, T. J. J. F. i. M. (2021). Mesoporous silica based nanostructures for bone tissue regeneration. 8, 692309.

Gopalakrishnan, A., Ram, M., Kumawat, S., Tandan, S., & Kumar, D. (2016). Quercetin accelerated cutaneous wound healing in rats by increasing levels of VEGF and TGF-β1.

Hahn, D. W., & Omenetto, N. J. A. s. (2010). Laser-induced breakdown spectroscopy (LIBS), part I: review of basic diagnostics and plasma–particle interactions: still-challenging issues within the analytical plasma community. 64(12), 335A-366A.

Han, J. H., Moon, Y., Lee, J. J., Choi, S., Kim, Y.-C., & Jeong, S. J. B. o. e. (2015). Differentiation of cutaneous melanoma from surrounding skin using laser-induced breakdown spectroscopy. 7(1), 57-66.

Jasim, S. A., Abdelbasset, W. K., Jawad, M. A., Bokov, D. O., Thangavelu, L., & Manouchehri, A. J. C. J. o. E. S. (2023). Tramadol toxicity phytotherapy: The protective role of medicinal plants against tramadol toxicity. 21(1), 227-243.

Jun, S.-K., Yang, S.-A., Kim, Y.-J., El-Fiqi, A., Mandakhbayar, N., Kim, D.-S., Roh, J., Sauro, S., Kim, H.-W., & Lee, J.-H. J. S. r. (2018). Multi-functional nano-adhesive releasing therapeutic ions for MMP-deactivation and remineralization. 8(1), 5663.

Kabir, M. H., Guindo, M. L., Chen, R., Sanaeifar, A., & Liu, F. J. F. (2022). Application of laser-induced breakdown spectroscopy and chemometrics for the quality evaluation of foods with medicinal properties: A review. 11(14), 2051.

Kang, M. S., Lee, N.-H., Singh, R. K., Mandakhbayar, N., Perez, R. A., Lee, J.-H., & Kim, H.-W. J. B. (2018). Nanocements produced from mesoporous bioactive glass nanoparticles. 162, 183-199.

Kargozar, S., Mozafari, M., Ghodrat, S., Fiume, E., Baino, F. J. M. S., & C, E. (2021). Copper-containing bioactive glasses and glass-ceramics: From tissue regeneration to cancer therapeutic strategies. 121, 111741.

Khalkhal, E., Rezaei-Tavirani, M., Zali, M. R., & Akbari, Z. J. J. o. l. i. m. s. (2019). The evaluation of laser application in surgery: a review article. 10(Suppl 1), S104.

Khan, M. I., Siddiqui, S., Barkat, M. A., Alhodieb, F. S., Ashfaq, F., Barkat, H. A., Alanezi, A. A., Arshad, M. J. J. o. T., & Medicine, C. (2022). Moringa oleifera leaf extract induces osteogenic-like differentiation of human osteosarcoma SaOS2 cells. 12(6), 608-618.

Khoshkam, V., Del Amo, F. S.-L., Monje, A., Lin, G.-h., Chan, H.-L., Wang, H.-L. J. I. J. o. O., & Implants, M. (2016). Long-term Radiographic and Clinical Outcomes of Regenerative Approach for Treating Peri-implantitis: A Systematic Review and Meta-analysis. 31(6).

Kim, D.-A., Lee, J.-H., Jun, S.-K., Kim, H.-W., Eltohamy, M., & Lee, H.-H. J. D. M. (2017). Sol–gel-derived bioactive glass nanoparticle-incorporated glass ionomer cement with or without chitosan for enhanced mechanical and biomineralization properties. 33(7), 805-817.

Kou, X., Li, B., Olayanju, J. B., Drake, J. M., & Chen, N. J. N. (2018). Nutraceutical or pharmacological potential of Moringa oleifera Lam. 10(3), 343.

Kumar, A., Yueh, F.-Y., Singh, J. P., & Burgess, S. J. A. o. (2004). Characterization of malignant tissue cells by laser-induced breakdown spectroscopy. 43(28), 5399-5403.

Lee, Y.-S., Kim, T.-Y., Kim, Y., Lee, S.-H., Kim, S., Kang, S. W., Yang, J.-Y., Baek, I.-J., Sung, Y. H., Park, Y.-Y. J. C. h., & microbe. (2018). Microbiota-derived lactate accelerates intestinal stem-cell-mediated epithelial development. 24(6), 833-846. e836.

Li, K., O'Dwyer, R., Yang, F., Cymerman, J., Li, J., Feldman, J. D., Simon, M., & Rafailovich, M. J. D. M. (2023). Enhancement of acellular biomineralization, dental pulp stem cell migration, and differentiation by hybrid fibrin gelatin scaffolds. 39(3), 305-319.

Meena, R., Prajapati, S., Nagar, R., Porwal, O., Nagar, T., Tilak, V., Jayakumararaj, R., Arya, R., Dhakar, R. J. A. J. o. D., & Sciences, H. (2021). Application of Moringa oleifera in Dentistry. 1(1), 10-13.

Meyer-Lueckel, H., Wierichs, R. J., Schellwien, T., & Paris, S. J. C. r. (2015). Remineralizing efficacy of a CPP-ACP cream on enamel caries lesions in situ. 49(1), 56-62.

Miziolek, A. W., Palleschi, V., & Schechter, I. (2006). Laser induced breakdown spectroscopy. Cambridge university press.

Morton, L. M., & Dover, J. S. J. D. S. (2014). Foreseeing the future of skin tightening. 40, S199-S202.

Niu, L.-n., Zhang, W., Pashley, D. H., Breschi, L., Mao, J., Chen, J.-h., & Tay, F. R. J. D. m. (2014). Biomimetic remineralization of dentin. 30(1), 77-96.

Noll, R., Noll, R. J. L.-I. B. S. F., & Applications. (2012). Material ablation. 97-118.

Padayachee, B., & Baijnath, H. J. S. A. J. o. B. (2020). An updated comprehensive review of the medicinal, phytochemical and pharmacological properties of Moringa oleifera. 129, 304-316.

Patel, K. D., El-Fiqi, A., Lee, H.-Y., Singh, R. K., Kim, D.-A., Lee, H.-H., & Kim, H.-W. J. J. o. M. C. (2012). Chitosan–nanobioactive glass electrophoretic coatings with bone regenerative and drug delivering potential. 22(47), 24945-24956.

Petrov, T., Pecheva, E., Walmsley, A. D., Dimov, S. J. M. S., & C, E. (2018). Femtosecond laser ablation of dentin and enamel for fast and more precise dental cavity preparation. 90, 433-438.

Qin, D., Wang, N., You, X.-G., Zhang, A.-D., Chen, X.-G., & Liu, Y. J. B. S. (2022). Collagen-based biocomposites inspired by bone hierarchical structures for advanced bone regeneration: Ongoing research and perspectives. 10(2), 318-353.

Qu, Y., Gu, T., Du, Q., Shao, C., Wang, J., Jin, B., Kong, W., Sun, J., Chen, C., Pan, H. J. A. B. S., & Engineering. (2020). Polydopamine promotes dentin remineralization via interfacial control. 6(6), 3327-3334.

Radziemski, L., & Cremers, D. J. S. A. P. B. A. S. (2013). A brief history of laser-induced breakdown spectroscopy: from the concept of atoms to LIBS 2012. 87, 3-10.

Ramakrishnaiah, R., Rehman, G. U., Basavarajappa, S., Al Khuraif, A. A., Durgesh, B., Khan, A. S., & Rehman, I. u. J. A. S. R. (2015). Applications of Raman spectroscopy in dentistry: analysis of tooth structure. 50(4), 332-350.

Reynolds, E. C. J. A. d. j. (2008). Calcium phosphate-based remineralization systems: scientific evidence? , 53(3), 268-273.

Ribas, R. G., Schatkoski, V. M., do Amaral Montanheiro, T. L., de Menezes, B. R. C., Stegemann, C., Leite, D. M. G., & Thim, G. P. J. C. I. (2019). Current advances in bone tissue engineering concerning ceramic and bioglass scaffolds: A review. 45(17), 21051-21061.

Saini, R. K., Sivanesan, I., & Keum, Y.-S. J. B. (2016). Phytochemicals of Moringa oleifera: a review of their nutritional, therapeutic and industrial significance. 6, 1-14.

Saran, R., Ginjupalli, K., George, S. D., Chidangil, S., & VK, U. J. H. (2023). LASER as a tool for surface modification of dental biomaterials: A review. 9(6).

Serbin, J., Bauer, T., Fallnich, C., Kasenbacher, A., & Arnold, W. J. a. s. s. (2002). Femtosecond lasers as novel tool in dental surgery. 197, 737-740.

Sharaha, U., Hania, D., Lapidot, I., Salman, A., & Huleihel, M. J. C. (2023). Early detection of pre-cancerous and cancerous cells using Raman spectroscopy-based machine learning. 12(14), 1909.

Singh, G., Passsari, A. K., Leo, V. V., Mishra, V. K., Subbarayan, S., Singh, B. P., Kumar, B., Kumar, S., Gupta, V. K., & Lalhlenmawia, H. J. F. i. P. S. (2016). Evaluation of phenolic content variability along with antioxidant, antimicrobial, and cytotoxic potential of selected traditional medicinal plants from India. 7, 407.

Singh, V. K., Sharma, J., Pathak, A. K., Ghany, C. T., & Gondal, M. J. B. r. (2018). Laser-induced breakdown spectroscopy (LIBS): a novel technology for identifying microbes causing infectious diseases. 10(5), 1221-1239.

Spicer, P. P., Kretlow, J. D., Young, S., Jansen, J. A., Kasper, F. K., & Mikos, A. G. J. N. p. (2012). Evaluation of bone regeneration using the rat critical size calvarial defect. 7(10), 1918-1929.

Tang, B., Huang, S., Fang, Y., Hu, J., Malonzo, C., Truhlar, D. G., & Stein, A. J. T. J. o. C. P. (2016). Mechanism of electrochemical lithiation of a metal-organic framework without redox-active nodes. 144(19).

Thapa, K., Poudel, M., & Adhikari, P. J. A. S. A. (2019). Moringa oleifera: A review article on nutritional properties and its prospect in the context of Nepal. 3(11), 47-54.

Vestergaard, A. H. (2014). Past and present of corneal refractive surgery: A retrospective study of long-term results after photorefractive keratectomy and a prospective study of refractive lenticule extraction Wiley Online Library].

Webb, A. J., & Rothwell, P. M. J. S. (2016). Magnetic resonance imaging measurement of transmission of arterial pulsation to the brain on propranolol versus amlodipine. 47(6), 1669-1672.

Xie, T., Zhou, L., Zhang, X., Sun, W., Ding, H., Liu, T., Gu, Y., Sun, C., Hu, F., & Zhu, W. J. W. N. (2017). Endoscopic supracerebellar transtentorial approach to atrium of lateral ventricle: preliminary surgical and optical considerations. 105, 805-811.