ORIGINAL RESEARCH

Evaluation of Clove and Ginger-mediated Titanium Oxide Nanoparticles-based Dental Varnish against *Streptococcus mutans* and *Lactobacillus* Species: An *In Vitro* Study

Jerry Joe Chokkattu[1], Ditty J Mary[2], Rajeshkumar Shanmugam[3], Singamsetty Neeharika[4]

Received on: 07 February 2023; *Accepted on:* 09 March 2023; *Published on:* 05 May 2023

Abstract

Aim: To study the mechanism of action of clove and ginger-mediated titanium oxide nanoparticles (TiO_2 NPs)-based dental varnish against *Streptococcus mutans* (*S. mutans*) and *Lactobacillus* species.

Materials and methods: Plant extract was prepared from ginger and clove, which was purchased locally and processed in a mixer grinder to create a fine powder. A total of 100 mL of distilled water was used to dissolve 0.5 gm of each of the powders, followed by cooking on a hotplate for 10 minutes at 60°C until it bubbled. The extract was collected, filtered, and stored. Dental varnish is prepared using a titration of 6.26 mm of titanium dioxide powder in 60 mL of distilled water was prepared followed by the addition of 40 mL of plant extract into an orbital shaker. Varied concentrations of dental varnish (25, 50, 100 µL) were introduced into culture well plates consisting of *S. mutans* and *Lactobacillus* followed by incubation. Antibacterial properties were analyzed through the recording of zones of inhibition, minimum inhibitory concentration (MIC), and minimum bacterial concentration.

Results: The results have demonstrated that when concentration rises, optical density values fall, demonstrating a bactericidal action. The results show a great difference between the values of optical density of the test samples at various concentrations in the order of 25, 50, and 100 µL being the highest when compared with control and antibiotic groups against *Streptococcus* and *Lactobacillus*. The results have proved that the greenly generated dental varnish has demonstrated good antibacterial and antibiofilm properties.

Conclusion: The results demonstrated that a dental varnish formulation based on TiO_2 NPs mediated by clove and ginger has proved to have an effective antibacterial action and should be further evaluated through *in vivo* studies too.

Clinical significance: Due to their effective antibacterial qualities, titanium dioxide nanoparticles have been used to create a dental varnish that works well when combined with natural compounds like ginger and clove. This varnish can be improved with further testing using *in vivo* simulations.

Keywords: Antimicrobial activity, Clove, Dental varnish, Ginger, Titanium oxide nanoparticle.

World Journal of Dentistry (2023): 10.5005/jp-journals-10015-2185

Introduction

Nanotechnology has developed significantly over the past 10 years, becoming an integral part of medical sciences due to its wide variety of applications in several concepts of health investigation and treatment.[1] Recent studies have demonstrated that metal nanoparticles have antibacterial capabilities. On the contrary, the functional characteristics of metal nanoparticles may be enhanced to complete the green manufacturing method.[2] Because of its pharmacological treatment and biodistribution activities, researchers are currently concentrating on nano-based pharmaceuticals, for instance, as a platform for the operational delivery of therapeutic molecules.[3]

Due to the use of noxious chemicals or other environmentally hazardous substances, it has been demonstrated that using nano-based pharmaceuticals to achieve conservative strategies equivalent to their physical and chemical ways is environmentally hazardous.[4] Researchers are increasingly concentrating on biological approaches that combine plants and their components, as well as microorganisms akin to fungus, algae, and bacteria, to finish the nontoxic, ecologically friendly procedure utilized to produce nanoparticles.[5]

Herbal or traditional derivatives are an ecofriendly alternative for carrying out subsequent procedures because of the movability and repeatability of created nanomaterials.[6] Algae, actinomycetes, sugar, ginger and clove, bacteria, and plants have all been successfully used to produce nanoparticles.[6,7] Plant-mediated synthesis of nanoparticles is cost-effective, can be measured

[1,2,4]Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

[3]Department of Pharmacology, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

Corresponding Author: Jerry Joe Chokkattu, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India, Phone: +91 9841026569, e-mails: jerryjoe@gmail.com, jerryjoe.sdc@saveetha.com

How to cite this article: Chokkattu JJ, Mary DJ, Shanmugam R, *et al.* Evaluation of Clove and Ginger-mediated Titanium Oxide Nanoparticles-based Dental Varnish against *Streptococcus mutans* and *Lactobacillus* Species: An *In Vitro* Study. World J Dent 2023;14(3):233–237.

Source of support: Nil

Conflict of interest: None

faster and with less correction, and without any implications of hazardous chemicals.[8] With a renewed interest in traditional medicine, plant-derived drugs are believed to be safer and more dependable in comparison with synthetic drugs with adverse side effects.[9] Syzygium aromaticum (clove) belongs to the Myrtaceae family, a native of Indonesian islands with eugenol as the main bioactive compound with concentrations ranging from 9381 to 14650 mg per 100 gm of freshly sourced plant material.[10] Studies conducted by Mohapatra et al. have proved clove to have bactericidal and fungicidal effects at concentrations of 1–3% against *Staphylococcus aureus* and other strains.[10] *Zingiber officinale* (*Z. officinale*) (ginger) is one of the most commonly used ingredients in herbal medicine for the purpose of gastric disorders, bleeding disorders, etc. It has also been proven to serve as an excellent bactericidal and catalytic agent.[11]

Among the various inorganic nanoparticles, selenium oxide, and TiO_2 stand the highest among global production volumes as they are the safest to use.[10] Physical, biological, chemical, and environmental-friendly approaches were used to organize TIO_2 NPs.[12] TIO_2 NPs have strong antibacterial properties and can be used to combat multidrug-resistant infections. TIO_2 NPs are particularly useful because of their high specific toxicity against bacteria and minimal toxicity toward humans.[13]

Enamel decalcification is followed by dentin decalcification in the chemomicrobial process known as dental caries.[14] The development of pathogenic plaque is aided by the cariogenic *Streptococcus* species. Large populations of *Streptococcus* and *Lactobacilli* contribute to dental caries and periodontal diseases.[15]

Various experiments have been conducted toward the synthesis and characterization of different properties of nanoparticles such as zinc oxide, zirconium oxide, selenium, halloysite nanotubes, silymarin/hydroxyapatite, chitosan nanocomposites, plant-derived silver NPs, nanoemulsions, and oleoresins.[16–27] Considering the abovementioned data, the aim of the current study is focussed on evaluating the mechanism of action of a new dental varnish formulation prepared by using TiO_2 NPs reinforced with ginger and clove against oral pathogens like *S. mutans* and *Lactobacilli* species with a null hypothesis that there is a significant difference in antibacterial action due to this new formulation across different concentrations by determining MIC.[28]

Materials and Methods

Study Setting

The study was carried out in the nanomedicine laboratory, Department of Pharmacology, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (deemed to be university), Chennai, Tamil Nadu, India, after obtaining approval from the Scientific Review Board (IHEC/SDC/UG-1921/21/130)

The bacterium *S. mutans* and *Lactobacillus acidophilus* were the oral pathogens used to test the antibacterial activity in the current study. The microorganisms were acquired from the nanobiomedicine laboratory culture lab at Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (deemed to be university), Chennai, Tamil Nadu, India.

Plant Extract Preparation

Around 20 gm of raw clove and ginger were purchased in the local market. The skin of the ginger was disintegrated, followed by sun-drying until its ready to be processed in a mixer grinder to create a fine powder. In 100 mL of distilled water, 0.5 gm of ginger and 0.5 gm of clove powder were added to dissolve. The solution was cooked in a hotplate for 10 minutes at 60°C until it bubbled. Later the plant extract was collected from the solution in a flask through a funnel using a Whatman filter. The extract was then overnight chilled in an airtight storage container.

Dental Varnish Preparation

In order to make dental varnish, a titration of 6.26 mm of TiO_2 powder in 60 mL of distilled water was prepared, followed by the addition of 40 mL of plant extract into an orbital shaker. Readings have been made to assess the color changes of the solution every 2 hours using ultraviolet–visible (UV) spectrophotometer. After 36 hours, centrifugation at 7000 rpm for 10 minutes was carried out for further analysis. TiO_2 NPs pellets enhanced with clove and ginger were created after centrifugation and were maintained as a stock solution, which will be diluted further as a working solution.

Evaluation of MIC

The classic broth dilution method was used to examine the antibacterial effectiveness of silver NPs by measuring how quickly microbes grew visibly in the Mueller–Hinton broth. The culture plates were sterilized and kept ready for inoculation. The bacteria availed from the laboratory was centrifuged at 11000 rpm for 5 minutes in the broth, followed by removal of supernatant and dilution with 20 mL of sterile saline. After overnight incubation, the cell density of bacterial culture in Mueller–Hinton broth was maintained at 108 colony-forming units per milliliter (CFU/mL) following McFarland's standard at an optical density of 0.10 at 625 nm. The TiO_2 NPs enhanced with clove and ginger were diluted with water in concentrations of 25, 50, and 100 µL. The test solution (25, 50, 100 µL) was serially added to culture plates containing a culture of *Lactobacillus* and *Streptococcus* species, followed by incubation at 37°C for 4 hours and examined for growth on 1 hourly basis (Fig. 1). The sampling method used is a convenience method and the number of test samples used is four at each concentration. To assess the medium sterility and quality of the test results, the samples were grouped into three that is test group, antibiotic or standard, and positive control group. The positive control consists of bacterial inoculated broth, which is incubated at 37°C, whereas the standard group consists of an undiluted dental varnish stock solution of TiO_2 NPs with bacterial inoculated broth. The values of MIC were recorded soon after the introduction of dental varnish at varied concentrations at 1 hourly time interval for 5 hours. This method is fabricated according to the doubling time of the bacteria used, which is approximately 1–1.5 hours for both, respectively. The series of dilution culture plates were checked for signs of microbial growth after incubation; these signs often included turbidity and/or the presence of a microbe pellet at the base of the vessel used for cell culture. In the dilution series, the last tube left without any growth was considered as MIC endpoint, and values were recorded before and after incubation.[29] The visible results are again validated under spectrophotometer by verifying the optical density of test samples at each concentration, positive control, and standard sample.

Minimum Bactericidal Concentration (MBC)

A pure culture of bacterium (*S. mutans* and *Lactobacillus acidophilus*) was diluted in Muller–Hinton broth to a concentration of 0.5 McFarland standards tube to promote growth. To a stock concentration that is around 100 times the expected MIC, the antimicrobial test substance was diluted. Further, the test microbe solution was diluted

Fig. 1: Antimicrobial activity of clove and ginger-mediated TiO_2 NPs-based dental varnish

using 96-well microtiter plates. The wells were inoculated with equal amounts of the indicated microbe to move from least concentrated to most concentrated. For each test microbe sample, positive and negative control was maintained either in a tube or a culture well to demonstrate acceptable microbial growth and the presence of sterile habitat over the period of the incubation time of 24 hours. Positive control under incubation was used to assess the baseline microorganism concentration,[30] in which the presence of turbidity indicates the development of the bacteria. The MIC was recorded as least when no noticeable growth/development in the bacteria was seen. The MBC was calculated by plating and counting the MIC of the dilution. When compared to the MIC dilution, the MBC showed the lowest bactericidal concentration indicating a drop in CFU/mL (such as 99.9%). The MIC and MBC values are assessed according to the bacterial growth as colonies and are interpreted as CFU/mL and as percentages when assessed for optical density. The results were collected in Microsoft Excel and were statistically plotted in Statistical Package for the Social Sciences software (IBM, India), version 22. In this study, the MBC result was statistically analyzed by analysis of variance (ANOVA) using descriptive statistics with mean and standard deviation. Later *post hoc* Tukey's analysis was also performed for MBC of TiO_2 NPs reinforced with ginger and clove against *S. mutans* and *Lactobacillus* with a predetermined statistical significance at $p < 0.05$.

Results

Visual Observation for *S. mutans* and *Lactobacillus*

After the incubation at 37°C under anaerobic conditions, it was noticed that the culture plates with 100 µL dilution of test solution showed minimal turbidity exhibiting bacterial growth inhibition to be dominant at that concentration. This was confirmed when the suspension from the 100 µL culture plate was added to a new culture plate with the broth and kept under incubation for 24 hours for MBC evaluation, demonstrating barely any bacterial growth. The average MBC values for the concentrations 25, 50, and 100 µL were 8, 4, and <1 µg/mL, respectively. The statistical analysis conducted for MBC of all test samples of all concentrations against *S. mutans* and *Lactobacilli* using ANOVA and *post hoc* Tukey's test showed significant inhibition of growth at 100 µL when compared to 25 and 50 µL.

Observations under Spectrophotometer

The optical density was evaluated in terms of absorbance at each concentration and at each time interval and is used to investigate the mechanism of action of TiO_2 NPs mediated by clove and ginger herbal formulation against *S. mutans* and *Lactobacillus acidophilus*. The amount of light scattering a bacterium in a culture plate is defined as optical density. The light scattering increases with the number of microorganisms. Figures 2 and 3 display the optical density of varied concentrations at each interval over the course of 4 hours tested against *S. mutans* and *Lactobacillus acidophilus*, respectively. It demonstrates that when concentration rises, optical density values fall, demonstrating an effective inhibitory action toward bacterial growth. The MIC was at 100 µL and was confirmed by MBC <1 µg/mL. The results show a great difference between the values of optical density of the test samples at various concentrations when compared with control and antibiotic groups when tested against *Streptococcus* and *Lactobacillus*.

Discussion

Dental caries is one of the most common oral problems with high incidence and prevalence and, if untreated, may lead to irreversible damage. Simply put, a biofilm over the tooth has the potential to initiate caries formation on the tooth surface due to various factors related to intra and extraoral. In an effort to incorporate antimicrobial compounds into the biofilm, a number of preventive measures and products have been developed for the maintenance of oral hygiene.[31]

In light of the rising interest in nanomaterials as drug delivery systems in contemporary technology, studies have shown that TiO_2 NPs are effective antibacterial agents against a variety of gram-positive and gram-negative pathogens because of their distinctive low adherence and significance for developing carious lesions. The current study evaluated the antibacterial and antibiofilm properties of TiO_2 NPs enhanced with natural extracts like ginger and clove in relation to bacteria (*S. mutans* and *Lactobacillus*). This new dental varnish formulation has exhibited promising antibacterial and antibiofilm properties.

Apart from TiO_2 NPs, various metal oxide NPs like zinc oxide, magnesium oxide, copper oxide, silicon dioxide, etc., have also proved to exhibit good antibacterial activity. Besides being less toxic, heat resistant, and highly effective against resistance microbe strains, they may also act as essential mineral supplements to the human body.[32]

Titanium dioxide nanoparticles (TiO_2 NPs) have been a friendly addition to adhesives and composite dental materials because of

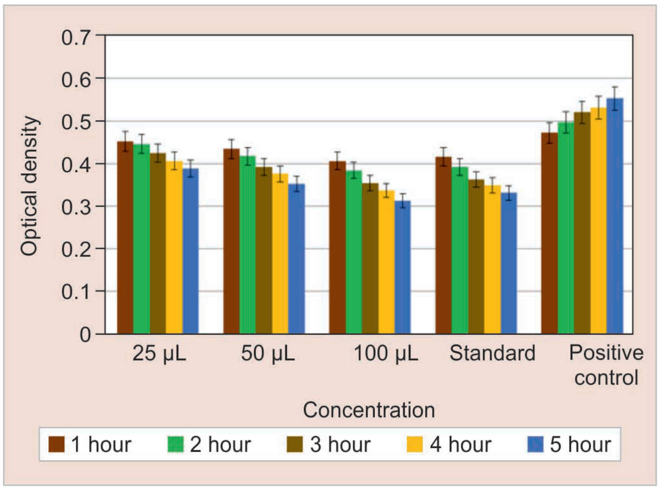

Fig. 2: Antimicrobial activity of clove and ginger-mediated TiO_2 NPs-based dental varnish against *S. mutans* tested at various concentrations from 25, 50, 100μL, and the percentage of inhibition. The X-axis shows the concentration of the Nps and the Y-axis shows the optical density

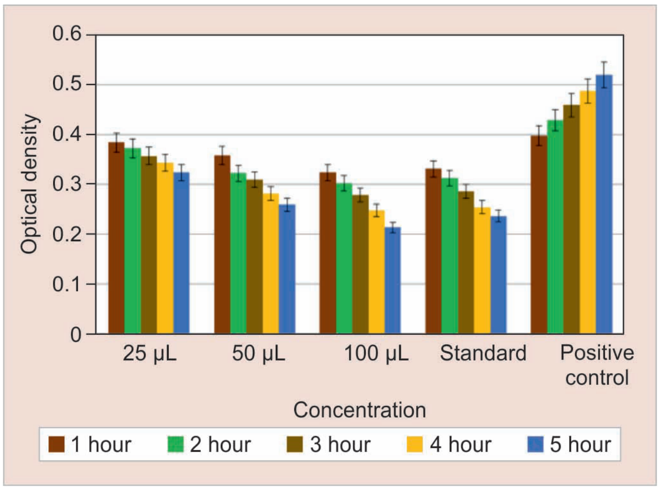

Fig. 3: Antimicrobial activity of clove and ginger-mediated TiO_2 NPs-based dental varnish against *Lactobacillus* species tested at various concentrations from 25, 50, 100μL, and the percentage of inhibition. The X-axis shows the concentration of the NPs and the Y-axis shows the optical density

their photocatalytic action, antibactericidal, and UV-absorbing qualities, which correlates with the results of the current study. On the contrary, due to their smaller nanometer scale and potent oxidizing capacity generating reactive oxygen species (ROS), TiO_2 NPs have been a superior choice while formulating materials in need of antibacterial properties. According to Sun et al., dental resins could incorporate acid-functionalized TiO_2 NPs, which could then be employed as dental adhesives on human teeth.[33] These NPs produce ROS when exposed to visible light, which may be used to accelerate the conversion rate of the vinyl component in the composite resins and produce adhesives with more powerful shear bindings with the natural teeth. Research on the toxic/damaging nature of NPs on the deoxyribonucleic acid and their possible release from dental composites revealed a minimal probability of carcinogenic consequences.

When the mechanical properties of the composites were evaluated, the use of TiO_2 as a reinforcement agent enhanced the polymer. The morphological findings showed that TiO_2 adhered strongly to the polymer matrices and that it was distributed uniformly inside them. TiO_2's mechanical properties were improved by the polymer matrix's adequate compatibility with TiO_2. Due to its photoactivity, the inorganic substance TiO_2 has recently received a lot of interest. In aqueous solutions, TiO_2 reacts with UV light to produce a number of ROS. Because photodynamic treatment has the ability to create ROS and hence cause cell death, it has been used to treat various clinical conditions ranging from psoriasis to cancer.

Numerous techniques to develop TiO_2 NPs reinforced with natural extracts have been researched to increase the effectiveness of anticancer and antibacterial medications. *Ficus benghalensis*, *Syzygium aromaticum*, *Z. officinale*, and *Azadirachta indica* twig extracts were used to create a new formulation along with TiO_2 NPs. Strong ketones like gingerol, which are frequently used in research, give ginger its distinctive flavor. It possesses a variety of biological qualities, like antibacterial, antioxidant, and anticancer, as well as those that boost the immune system. Another natural ingredient like clove consists of eugenol, which is the most bioactive component showing great antibacterial properties against bacterial and fungal stains.[34] Considering the abovementioned evidence, the current study designed a dental varnish with a new formulation using ginger and clove as one the natural resources for antibacterial properties, which was supported strongly by the results.

Due to their distinctive property of low adherence and relevance toward the progression of carious lesions, studies have demonstrated the antibacterial activity of TiO_2 NPs against a variety of gram-positive and gram-negative pathogens.[34] The best bacteria to examine the formulation's antibacterial effectiveness are *Lactobacilli* followed by *Streptococcus*, due to which the current study is conducted against the abovementioned bacterium.

Limitations

The study was conducted under *in vitro* environment with minimal test samples. Hence the results of the antibacterial efficacy alone may not be effective in proving its clinical efficacy.

Scope of future research—further *ex vivo*-based research and clinical trials are needed to determine the exact mechanism of action of these NPs against other pathogens.

Conclusion

Antimicrobial activity and mechanism of action against *S. mutans* and *Lactobacillus* species with the clove and ginger-mediated TiO_2 NPs-based dental varnish was studied. These extracts could be employed as a dental varnish with high efficacy if features such as tissue tolerance can be explored.

Acknowledgments

The authors thank their sincere gratitude to Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (deemed to be university), Chennai, Tamil Nadu, India, for their constant support in carrying out this research.

Financial Support and Sponsorship

The present study is funded by the Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (deemed to be university), Chennai, Tamil Nadu, India, M/s Trend Fashions India Pvt Ltd.

References

1. Ghorbanpour M, Bhargava P, Varma A, et al. Biogenic nanoparticles and their use in agro-ecosystems. Springer Nature; 2020. 606 p.
2. Venditti I. Nanostructured materials based on noble metals for advanced biological applications. Nanomaterials (Basel) 2019;9(11):1593. DOI: 10.3390/nano9111593
3. Rai M, Duran N. Metal Nanoparticles in Microbiology. Springer Science & Business Media; 2011. 306 p.
4. Emam HE, Ahmed HB. Carboxymethyl cellulose macromolecules as generator of anisotropic nanogold for catalytic performance. Int J Biol Macromol 2018;111:999–1009. DOI: 10.1016/j.ijbiomac.2018.01.111
5. Iravani S, Shukla AK. Plant protein-based nanoparticles and their biomedical applications. Nanomaterials and Plant Potential 2019:177–191. DOI: 10.1007/978-3-030-05569-1_6
6. Horikoshi S, Serpone N. Microwaves in Nanoparticle Synthesis: Fundamentals and Applications. John Wiley & Sons; 2013. 352 p.
7. Kanchi S, Ahmed S. Green Metal Nanoparticles: Synthesis, Characterization and their Applications. John Wiley & Sons; 2018. 716 p.
8. Maddela NR, Chakraborty S, Prasad R. Nanotechnology for Advances in Medical Microbiology. Springer; 2022. 427 p.
9. Aravind A, Mathai K, Anand S, et al. Antimicrobial effect of ginger, garlic, honey, and lemon extracts on Streptococcus mutans. J Contemp Dent Pract 2017;18(11):1004–1008. DOI: 10.5005/jp-journals-10024-2165
10. Mohapatra S, Leelavathi L, I MA, et al. Assessment of antimicrobial efficacy of zinc oxide nanoparticles synthesized using clove and cinnamon formulation against oral pathogens - an in vitro study. J Evol Med Dent Sci 2020;9(29):2034–2039. DOI: 10.14260/jemds/2020/443
11. Haider A, Ijaz M, Ali S, et al. Green synthesized phytochemically (zingiber officinale and allium sativum) reduced nickel oxide nanoparticles confirmed bactericidal and catalytic potential. Nanoscale Res Lett 2020;15(1):50. DOI: 10.1186/s11671-020-3283-5
12. Poddar M, Lakshmi GBV, Sharma M, et al. Environmental friendly polyacrylonitrile nanofiber mats encapsulated and coated with green algae mediated titanium oxide nanoparticles for efficient oil spill adsorption. Mar Pollut Bull 2022;182:113971. DOI: 10.1016/j.marpolbul.2022.113971
13. Wall V, King SC, Kashanchi GN, et al. Understanding the effect of nanoparticle size on thermal conductivity in amorphous nanoporous materials made from colloidal building blocks. J Phys Chem C 2022;126:18029–18035. DOI: 10.1021/acs.jpcc.2c05444
14. Hull MS, Bowman DM. Nanotechnology environmental health and safety—learning from the past, preparing for the future. Nano Environ Health Safety 2018:3–10. DOI: 10.1016/b978-0-12-813588-4.00001-4
15. Calvo F. Nanoalloys: From Fundamentals to Emergent Applications. Elsevier; 2020. 524 p.
16. Dhanraj G, Rajeshkumar S. Anticariogenic effect of selenium nanoparticles synthesized using brassica oleracea. J Nanomater 2021;11:1–9. DOI: 10.1155/2021/8115585
17. Selvaraj A, George AM, Rajeshkumar S. Efficacy of zirconium oxide nanoparticles coated on stainless steel and nickel titanium wires in orthodontic treatment. Bioinformation 2021;17(8):760–766. DOI: 10.6026/97320630017760
18. Rajeshkumar S, Santhoshkumar J, Jule LT, et al. Phytosynthesis of titanium dioxide nanoparticles using king of bitter Andrographis paniculata and its embryonic toxicology evaluation and biomedical potential. Bioinorg Chem Appl 2021;2021:6267634. DOI: 10.1155/2021/6267634
19. Rajeshkumar S, Vanaja M, Kalirajan A. Degradation of toxic dye using Phytomediated copper nanoparticles and its free-radical scavenging potential and antimicrobial activity against environmental pathogens. Bioinorg Chem Appl 2021;2021:1222908. DOI: 10.1155/2021/1222908
20. Chaithanya M, Maheswari TN Uma, Shanmugam R. Anti-inflammatory and antioxidant activity of lycopene, raspberry, green tea herbal formulation mediated silver nanoparticle. J Indian Acad Oral Med Radiol 2021;33(4):397. DOI: 10.4103/jiaomr.jiaomr_98_21
21. Subramanian AK, Prabhakar R, Vikram NR, et al. In vitro anti-inflammatory activity of silymarin/hydroxyapatite/chitosan nanocomposites and its cytotoxic effect using brine shrimp lethality assay. J Popul Ther Clin Pharmacol 2022;28(2):e71–e77. DOI: 10.47750/jptcp.2022.874
22. Rajeshkumar S, Santhoshkumar J, Vanaja M, et al. Evaluation of Zebrafish toxicology and biomedical potential of Aeromonas hydrophila mediated copper sulfide nanoparticles. Oxid Med Cell Longev 2022;2022:7969825. DOI: 10.1155/2022/7969825
23. Mi XJ, Choi HS, Perumalsamy H, et al. Biosynthesis and cytotoxic effect of silymarin-functionalized selenium nanoparticles induced autophagy mediated cellular apoptosis via downregulation of PI3K/Akt/mTORpathwayingastriccancer.Phytomedicine2022;99:154014. DOI: 10.1016/j.phymed.2022.154014
24. Ganapathy D, Shanmugam R, Pitchiah S, et al. Potential applications of halloysite nanotubes as drug carriers: a review. J Nanomater 2022;2022:1–7. DOI: 10.1155/2022/1068536
25. Nagalingam M, Rajeshkumar S, Balu SK, et al. Anticancer and antioxidant activity of Morinda citrifolia leaf mediated selenium nanoparticles. J Nanomater 2022;2022:1–7. DOI: 10.1155/2022/2155772
26. Perumalsamy H, Shanmugam R, Kim JR, et al. Nanoemulsion and encapsulation strategy of hydrophobic oregano essential oil increased human prostate cancer cell death via apoptosis by attenuating lipid metabolism. Bioinorg Chem Appl 2022;2022:9569226. DOI: 10.1155/2022/9569226
27. Ganapathy D, Shivalingam C, Shanmugam R, et al. Recent breakthrough of bismuth-based nanostructured materials for multimodal theranostic applications. J Nanomater 2022;2022:1–7. DOI: 10.1155/2022/4944320
28. Gütgemann F, Müller A, Churin Y, et al. Proposal of a method for harmonized broth microdilution antimicrobial susceptibility testing of Avibacterium gallinarum. J Clin Microbiol 2022;60(8):e0041922. DOI: 10.1128/jcm.00419-22
29. Kowalska-Krochmal B, Dudek-Wicher R. The minimum inhibitory concentration of antibiotics: methods, interpretation, clinical relevance. Pathogens 2021;10(2):165. DOI: 10.3390/pathogens10020165
30. Senghoi W, Klangbud WK. Antioxidants, inhibits the growth of foodborne pathogens and reduces nitric oxide activity in LPS-stimulated RAW 264.7 cells of nipa palm vinegar. PeerJ 2021;9:e12151. DOI: 10.7717/peerj.12151
31. Weng L, Wu L, Guo R, et al. Lactobacillus cell enveloped coated nanoparticles for antibiotic delivery against cariogenic biofilm and dental caries. J Nanobiotechnology 2022;20(1):356. DOI: 10.1186/s12951-022-01563-x
32. Ahmed FY, Farghaly Aly U, Abd El-Baky RM, et al. Comparative study of antibacterial effects of titanium dioxide nanoparticles alone and in combination with antibiotics on mdr pseudomonas aeruginosa strains. Int J Nanomedicine 2020;15:3393–3404. DOI: 10.2147/IJN.S246310
33. Yu Y, Kang L, Sun L, et al. Bimetallic Pt-Ni nanoparticles confined in porous titanium oxide cage for hydrogen generation from NaBH hydrolysis. Nanomaterials (Basel) 2022;12(15):2550. DOI: 10.3390/nano12152550
34. Ramya G, Rajasekar A. Enhanced antibacterial effect of titanium dioxide nanoparticles mediated grape seed extract on oral pathogens - streptococcus mutans and lactobacillus. J Evol Med Dent Sci 2021;10(22):1656–1661. DOI: 10.14260/jemds/2021/344