International Journal of
Medical Research and Surgery
IJMRS

Review Article

Mohammad H. K, et al., IJMRS @ PubScholars 2024, 1:6

Advancing Biological Research with Molybdenum Disulfide: A Detailed Review

Mohammad Hossein Karami[1]* **, Majid Abdouss**[2]

Department of Chemistry, Amirkabir University of Technology, P.O. Box 15875-4413, Tehran, Iran

Correspondence to: Mohammad Hossein Karami, Department of Chemistry, Amirkabir University of Technology, P.O. Box 15875-4413, Tehran, Iran

Received date: June 21, 2024; **Accepted Date:** June 28, 2024; **Published Date:** July 28, 2024

Citation: Mohammad H. Karami, Majid A. (2024) Advancing Biological Research with Molybdenum Disulfide: A Detailed Review, IJMRS @ PubScholars Group, *2024 ;1(6) : pp: 39-42*

Abstract

The intricate interplay between nanomaterials and biology holds paramount importance in ensuring safety and efficacy in biological applications. Molybdenum disulfide (MoS2), characterized by its flat and minuscule structure, exhibits favorable properties for biological utilization due to its non-toxic nature. This review delves into the interactions of MoS2 nanomaterials with large biomolecules and their implications for safety and novel chemical synthesis. Understanding the intricate interactions of 2D nanomaterials with biological systems at the molecular level is crucial. This knowledge allows us to assess their safety profile and explore their potential applications in chemistry. By comprehensively understanding these interactions, we can determine the safety and appropriate utilization of these nanomaterials in chemical processes. Thus, this information serves as a valuable tool for evaluating their safety and guiding their application in chemistry.

Keywords:
Interaction of MoS2, Antibacterial, Wound Therapy, Biological Safety, Biocompatibility

Introduction

Nano materials such as graphene, phosphorene, and MoS2 hold great potential for medical applications. The arrangement of MoS2 significantly influences its behavior. MoS2 exhibits varied crystal structures depending on the arrangement of its atoms [1]. The unique structure of these nanomaterials facilitates drug delivery, tissue engineering, and antibacterial activity. The precise interaction between MoS2 and biomolecules at the atomic level plays a crucial role in its compatibility with biological systems and its potential medical applications. However, excessive use of MoS2 may pose risks to human health[2]. Certain individuals speculate that the morphology of MoS2 could impact its mobility within the body, potentially leading to accumulation in the liver and spleen. The anticipation and oversight of nano-bio technology can mitigate potential risks[3].

These intelligent interactions also influence the adhesion and reactivity of biomolecules on MoS2 surfaces, ultimately dictating the efficacy of the nanomaterial. Understanding these intricate dynamics can aid in enhancing drug delivery systems, deciphering protein sequences, and engineering antibacterial fabrics. Various non-covalent forces govern the interaction between MoS2 and biomolecules[4]. While some researchers have explored the biological interactions of MoS2 at a microscopic level, further research is necessary to fully realize its potential for medical applications[5].

Thorough descriptions of both experimental procedures and computational methodologies are crucial when exploring the biological applications of molybdenum disulfide (MoS2). In research settings, the synthesis of MoS2 samples involves precise preparation techniques such as chemical vapor deposition (CVD), hydrothermal synthesis, or mechanical exfoliation[6]. These methods yield MoS2 with varying morphologies, layer thicknesses, and crystal structures, which significantly influence its behavior in biological systems. Following synthesis, MoS2 samples undergo meticulous characterization using advanced techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Raman spectroscopy[7]. These analytical methods provide detailed insights into the morphology, crystallinity, layer thickness, and structural properties of MoS2, ensuring the consistency and quality of the material used in biological studies. Additionally, computational models play a vital role, particularly when exploring the interactions between MoS2 and biological components[8]. Density functional theory (DFT) calculations are commonly employed to investigate MoS2's electronic structure, energetics, and bonding characteristics at the atomic level. DFT predictions encompass various properties of MoS2, including bandgap, charge transfer behavior, and adsorption characteristics, all of which are essential for understanding its biological interactions[9-11]. Moreover, molecular dynamics (MD) simulations are utilized to explore MoS2's dynamic behavior in biological environments. These simulations provide insights into MoS2's interactions with biological entities such as membranes, proteins, or other biomolecules over time, elucidating its stability, toxicity, and potential biomedical applications[12]. In summary, detailed descriptions of experimental setups and computational methodologies, including the utilization of techniques like DFT and MD simulations, bolster the reliability and reproducibility of research on MoS2's biological potential. These approaches facilitate a comprehensive understanding of MoS2's molecular behavior and its implications for biocompatibility and biomedical applications [13]. This study highlights significant aspects regarding the utilization of molybdenum disulfide nanoparticles in biotechnology. In the subsequent sections, we will briefly explore the significant applications of molybdenum disulfide nanoparticles (Fig1).

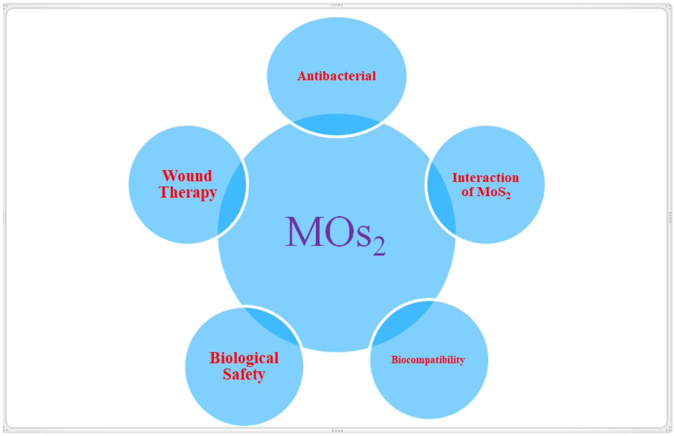

Fig1. Key applications of MoS2

2. Interaction of MoS2 with Various Biomolecules

The interaction between modest particles and 2D nanomaterials is crucial in determining the safety of these materials for living organisms[12]. However, conventional methods face challenges in accurately tracking how biomolecules adhere to nanoscale surfaces or undergo structural changes. Density functional theory and molecular dynamics simulations provide valuable insights into the intricate interactions between molecules, offering a detailed understanding of their binding mechanisms[13]. These techniques are commonly employed to investigate molecular interactions and comprehend extremely small systems. This approach elucidates the diverse molecular interactions with MoS2 nanomaterials and their potential applications in various fields[14].

3. Antibacterial and Wound Therapy

Understanding how MoS2 interacts with biological membranes is crucial as it impacts cell behavior, environmental effects, and the properties of MoS2 nanomaterials. With harmful microorganisms increasingly developing resistance to antibiotics, there's a growing need for new materials capable of effectively combating them while minimizing the risk of resistance[15]. Previous research has demonstrated the potent antibacterial properties of 2D nanomaterials like MoS2. Studies conducted by Liu and Roy's groups revealed that MoS2 nanosheets effectively eliminate both Gram-positive and Gram-negative bacteria[16]. The antimicrobial mechanism involves the interaction of the antibacterial agent wit hlipid membranes and MoS2 through electrical attraction and weak forces, leading to membrane disruption and leakage of cytoplasmic contents. Additionally, MoS2 inhibits specific cellular processes, including metabolism and respiration, and induces oxidative stress to enhance antimicrobial activity[17]. Further research by Jaiswal et al. resulted in the development of a novel wound-cleansing material based on MoS2.

This material effectively eradicates harmful bacteria while promoting wound healing without inducing resistance. The antibacterial mechanism involves a combination of chemical action and pore formation in bacterial membranes[18].

In summary, the interaction between MoS2 and biological membranes is pivotal for its antibacterial efficacy. By disrupting membrane integrity and facilitating oxygen and heat treatment, MoS2-based materials hold promise for future wound cleaning and treatment applications [19]. The scientists developed a composite hydrogel possessing photothermal antibacterial characteristics, which comprises a blend of dopamine-assisted exfoliated MoS2 (MoS2@PDA) and modified chitosan. Initially, dopamine is applied onto the MoS2 surface to improve its biocompatibility and photothermal features (Fig2)[20].

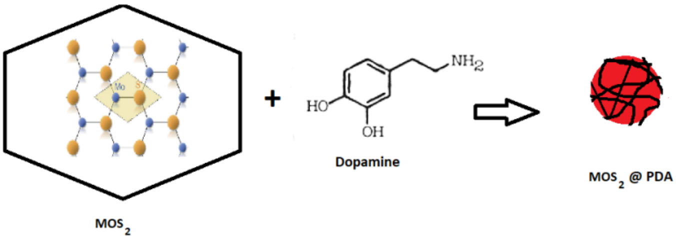

Fig2. Depicts the exfoliation process of MoS2@PDA

To overcome chitosan's poor solubility in water, we synthesized lipoic acid modified chitosan (LAMC). Following this, MoS2@PDA is dispersed into the LAMC solution. The resulting LAMC-MoS2@PDA hydrogel is injectable and solidifies under UV light (365 nm), enabling the elimination of pathological bacteria through NIR irradiation and promoting improved wound healing. The results indicate that the composite hydrogel effectively eliminates bacteria by generating heat and scavenging reactive oxygen species (ROS), thereby enhancing the wound healing process[21].

Another study investigated the use of biocompatible L-cysteine capped MoS2 nanoflowers for antibacterial applications, aiming to understand the underlying mechanisms. Antibacterial tests using the broth dilution method showed that these nanofibers effectively inhibited the growth of both gram-negative and gram-positive bacterial strains in a concentration and time-dependent manner[22]. Incubation with 250 µg/mL of MoS2-cys NFs for 6 hours led to over 90% inhibition of E. coli and S. aureus, confirming their potent antibacterial properties. Mechanistic insights suggest that the increased interaction sites and thin nanosheets of MoS2-cys NFs contribute to enhanced antibacterial activity, attributed to membrane damage, ROS-dependent, and ROS-independent oxidative stresses. Furthermore, toxicity studies affirmed the high biocompatibility of MoS2-cys NFs. In Figure 3, the bactericidal activity is demonstrated[23].

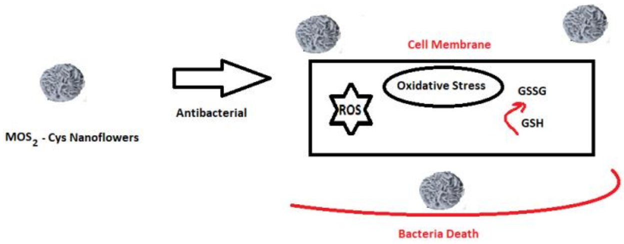

Fig 3. Depicts the bactericidal activity

4. Safety of MoS2

As the use of MoS2 nanomaterials in medicine becomes increasingly widespread, researchers are investigating their safety and efficacy for various applications, including wound treatment and internal use. Subsequent evaluations have been conducted to assess the safety profile and potential hazards associated with MoS2 in living organisms [24]. Studies have revealed that MoS2 nanosheets exhibit low toxicity towards different cell types in laboratory settings, with exfoliated MoS2 and WS2 demonstrating lower toxicity compared to materials such as graphene oxide. Moreover, investigations on human cells have indicated that fullerene-like MoS2 is non-toxic [25]. When combined with other nanomaterials, MoS2 exhibits enhanced performance and contributes to advancements in medical research. For instance, the integration of beneficial nanomaterials into MoS2 nano-composites enables targeted drug delivery, improved imaging capabilities, enhanced tissue healing, and precise medical treatments [26-28]. Generally, the safety and compatibility of MoS2 nanomaterials hinge on their intrinsic properties, which can be modified by adjusting their size and shape, employing biocompatible polymer coatings, incorporating biomolecules on the surface, and developing composite materials. These modifications expand the potential medical applications of MoS2 while enhancing its interaction with biological substances, thereby improving safety and efficacy [29-30].

5.Conclusions

Small materials entering the bloodstream interact with biomolecules, forming "protein crown" complexes. This interaction influences the behavior of nanoparticles in the body, including their movement, the body's response to them, and their elimination from the body. Studying the long-term health effects of MoS2-based nanomaterials is challenging due to the complexity of organic frameworks. Understanding the cellular and physiological responses to MoS2 at the microscopic level is crucial. While numerous studies have contributed to our understanding of nanomaterial safety, further research using laboratory experiments, studies in living organisms, and real-world environments is essential. Investigating how tiny biological entities interact with materials can aid in the development of new medical materials. Careful and expedient use of MoS2 and other nanomaterials is paramount in medical and scientific domains.

6.CRediT authorship contribution statement

Mohammad Hossein Karami: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Majid Abdouss: Supervision, Validation. Behzad Aghabarari: Supervision, Validation.

7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8.References

[1] Tan, L.F.; Wang, S.P.; Xu, K.; Liu, T.L.; Liang, P.; Niu, M.; Fu, C.H.; Shao, H.B.; Yu, J.; Ma, T.C.; et al. Layered MoS2 hollow spheres for highly-efficient photothermal therapy of rabbit liver orthotopic transplantation tumors. Small 2016, 12, 2046–2055.

[2] Yuan, Z.; Tao, B.L.; He, Y.; Liu, J.; Lin, C.C.; Shen, X.K.; Ding, Y.; Yu, Y.L.; Mu, C.Y.; Liu, P.; et al. Biocompatible MoS2/PDA-RGD coating on titanium implant with antibacterial property via intrinsic ROS-independent oxidative stress and NIR irradiation. Biomaterials 2019, 217, 119290.

[3] Wu, H.H.; Yang, R.; Song, B.M.; Han, Q.S.; Li, J.Y.; Zhang, Y.; Fang, Y.; Tenne, R.; Wang, C. Biocompatible inorganic fullerene-like molybdenum disulfide nanoparticles produced by pulsed laser ablation in water. ACS Nano 2011, 5, 1276–1281.

[4] Karami MH, Abdouss M, Rahdar A, Pandey , Graphene quantum dots: background, synthesis methods, and applications as nanocarrier in drug delivery and cancer treatment: an updated review. Inorg Chem Commun. 2024;161: 112032.

[5] Li J, Li M, Tang J, Li X, Zhang H, Zhang Y. Resonance light-scattering spectrometric study of interaction between enzyme and MPA-modified CdTe nanoparticles. Spectrochim Acta A Mol Biomol Spectrosc. 2008;70(3):514- 518.

[6] Hami Z. A Brief Review on Advantages of Nano-based Drug Delivery Systems. Ann Mil Health Sci Res. 2021; 19(1):e112274.

[7] Gelperina S, Kisich K, Iseman MD, Heifets L. The potential advantages of nanoparticle drug delivery systems in chemotherapy of tuberculosis. Am J Respir Crit Care Med. 2005;172(12):1487-1490.

[8] Parodi A, Haddix SG, Taghipour N, Scaria S, Taraballi F, Cevenini A, et al. Bromelain surface modification increases the diffusion of silica nanoparticles in the tumor extracellular matrix. ACS nano. 2014;8(10):9874-9883.

[9] Karami MH, Abdouss M. Cutting-edge tumor nanotherapy: Advancements in 5-fluorouracil Drug-loaded chitosan nanoparticles, Inorganic Chemistry Communications,2024; 164:112430.

[10] Khan S, Rizvi SMD, Avaish M, Arshad M, Bagga P, Khan MS. A novel process for size controlled biosynthesis of gold nanoparticles using bromelain. Mater Lett. 2015;159:373-376.

[11] de Sousa IP, Cattoz B, Wilcox MD, Griffiths PC, Dalgliesh R, Rogers S, et al. Nanoparticles decorated with proteolytic enzymes, a promising strategy to overcome the mucus barrier. Eur J Pharm Biopharm. 2015;97:257-264.

[12] Roy, S.; Haloi, P.; Choudhary, R.; Chawla, S.; Kumari, M.; Konkimalla, V.B.; Jaiswal, A. Quaternary pullulan-functionalized 2D MoS2 glycosheets: A potent bactericidal nanoplatform for efficient wound disinfection and healing. ACS Appl. Mater. Interfaces, 2023, 15, 24209–24227.

[13] Ataide JA, Gérios EF, Cefali LC, Fernandes AR, Teixeira MdC, Ferreira NR, et al. Effect of Polysaccharide Sources on the Physicochemical Properties of Bromelain–Chitosan Nanoparticles. Polymers. 2019;11(10):1681.

[14] Kammona O, Kiparissides C. Recent advances in nanocarrier-based mucosal delivery of biomolecules. J Control Release. 2012;161(3):781-794.

[15] Lü JM, Wang X, Marin-Muller C, Wang H, Lin PH, Yao Q, et al. Current advances in research and clinical applications of PLGA-based nanotechnology. Expert Rev Mol Diagn. 2009;9(4):325-341.

[16] Nagpal K, Singh SK, Mishra DN. Chitosan nanoparticles: a promising system in novel drug delivery. Chem Pharm Bull. 2010;58(11):1423-1430.

[17] Karami MH, Pourmadadi M, Abdouss M, Kalaee MR, Moradi O, et al. Novel chitosan/γ-alumina/ carbon quantum dot hydrogel nanocarrier for targeted drug delivery. Int J Biol Macromol.2023; 251:126280.

[18] Karami M H, Abdouss M , Assessing Particle Size and Surface Charge in Drug Carrier Nanoparticles for Enhanced Cancer Treatment: A Comprehensive Review Utilizing DLS and Zeta Potential Characterization. PSPRJ.2024; 5(3): 000615.

[19] Brito AM, Oliveira V, Icimoto MY, Nantes-Cardoso IL. Collagenase activity of bromelain immobilized at gold nanoparticle interfaces for therapeutic applications. Pharmaceutics. 2021;13(8):1143.

[20] Wang Y, Liu K, Huang K, Wei W, Huang Y, Dai H. Photothermal antibacterial MoS2 composited chitosan hydrogel for infectious wound healing, Biomaterials Advances, 2024;156:213701,

[21] Karami M H, Abdouss M , Recent advances of carbon quantum dots in tumor imaging. Nanomed J.2024; 11(1): 13-

[22] Karami M H, Abdouss M ,Maleki B. The State of the Art Metal Nanoparticles in Drug Delivery Systems: A Comprehensive Review Nanomed J.2024, Article in press.

[23] Kaushik R, Nandi S, Mandal M, Nath Gupta A. Biocompatible l-Cysteine-Capped MoS2 Nanoflowers for Antibacterial Applications: Mechanistic Insights, ACS Applied Nano Materials 2024; 7 (7): 7753-7765.

[24] Hirche C, Almeland SK, Dheansa B, Fuchs P, Governa M, Hoeksema H, et al. Eschar removal by bromelain based enzymatic debridement (Nexobrid®) in burns: European consensus guidelines update. Burns. 2020;46(4):782-796.

[25] Li, F.; Cui, X.T.; Zheng, Y.L.; Wang, Q.; Zhou, Y.L.; Yin, H.S. Photoelectrochemical biosensor for DNA formylation based on WS2 nanosheets@polydopamine and MoS2 nanosheets. Biosens. Bioelectron. X 2022, 10, 100104.

[26] Ghensi P, Cucchi A, Bonaccorso A, Ferroni L, Gardin C, Mortellaro C, et al. In vitro effect of bromelain on the regenerative properties of mesenchymal stem cells. J Craniofac Surg. 2019;30(4):1064-1067.

[27] Singer AJ, Taira BR, Anderson R, McClain SA, Rosenberg L. The effects of rapid enzymatic debridement of deep partialthickness burns with Debrase® on wound reepithelialization in swine. J Burn Care Res. 2010;31(5):795-802.

[28] Karami MH, Abdouss M, Karami M , Evaluation of in vitro and ex vivo models for studying the effectiveness of vaginal drug systems in controlling microbe infections: A systematic review. Clin J Obst Gynecol.2023; 6: 201-215.

[29] Miranda ÍKSPB, Santana FR, Camilloto GP, Detoni CB, Souza FVD, de Magalhães Cabral-Albuquerque EC, et al. Development of membranes based on carboxymethyl cellulose/acetylated arrowroot starch containing bromelain extract carried on nanoparticles and liposomes. J Pharm Sci. 2021;110(6):2372-2378.

[30] Bayat S, Zabihi AR, Farzad SA, Movaffagh J, Hashemi E, Arabzadeh S, et al. Evaluation of debridement effects of bromelain-loaded sodium alginate nanoparticles incorporated into chitosan hydrogel in animal models. Iran J Basic Med Sci. 2021;24(10):1404.