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Research and Reviews in Nanotechnology
Volume I

Editors:
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Mrs. Priyanka
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PREFACE

Nanotechnology, the study and manipulation of matter at the nanoscale, has emerged as a cornerstone of modern scientific inquiry. At this scale, materials exhibit unique properties and behaviors, offering unprecedented opportunities for advancement in diverse domains ranging from medicine and electronics to energy and environmental sustainability.

This book serves as a compendium of cutting-edge research, insightful reviews, and thought-provoking perspectives from experts and scholars at the forefront of nanotechnology. Through its pages, readers will encounter a diverse array of topics, from fundamental principles of nanoscale phenomena to the latest breakthroughs in nanomaterials synthesis, characterization, and applications.

The interdisciplinary nature of nanotechnology underscores its significance as a catalyst for interdisciplinary collaboration and cross-pollination of ideas. As such, this volume reflects the collaborative efforts of researchers from various disciplines, including physics, chemistry, materials science, engineering, biology, and medicine, among others. It is through this interdisciplinary lens that we gain deeper insights into the multifaceted nature of nanotechnology and its profound implications for science, technology, and society.

As editors, we are honored to present this compilation of contributions, which we believe will inspire, inform, and stimulate further inquiry into the fascinating realm of nanotechnology. We extend our gratitude to the authors for their scholarly contributions and to the readers for their interest and engagement in this exciting field.

May this volume serve as both a testament to the remarkable progress achieved thus far in nanotechnology and a harbinger of the boundless possibilities that lie ahead.

Editors

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NANOTECHNOLOGY- A SCIENTOMETRIC REVIEW

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Abstract:

In this area, there is a scope to analyze the bulk of the research output available which could be categorized to decide the next steps and identify research gaps. Therefore, the scientometric approach was carried out in this study, by VOS viewer to identify the trends and problems associated in this research area. Based on a Web of Science database search, 16393 documents were retrieved for Nanotechnology from Web of Science Core Collection and they were systematically screened out from 2014 to 2023. The documents were reviewed for co-authorship, collaboration with nations, co-occurrence of keywords, and institutional collaboration. The data showed that the studies released had an upward trend over the study period. In this study, an extensive analysis of the status of research and developments in Nanotechnology is provided along with the feedback on possible research directions.

Keywords: Nanotechnology, Nano materials, VOS viewer

Introduction:

Nanotechnology is the science and engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high-performance products. Nanotechnology is the manipulation of matter on a near-atomic scale to produce new structures, materials and devices. The technology promises scientific advancement in ‘n’number of sectors such as medicine, consumer products, energy, materials and manufacturing[(1)].

Nanotechnology was first seeded in 1959 by Richard Feynmann Physicist. There's plenty of room at the bottom**,** in which he described the possibility of synthesis via direct manipulation of atoms.

The term "nano-technology" was first used by Norio Taniguchi in 1974, though it was not widely known. Inspired by Feynman's concepts, K. Eric Drexler used the term "nanotechnology" in his 1986 book Engines of Creation: The Coming Era of Nanotechnology, which proposed the idea of a nanoscale "assembler" which would be able to build a copy of itself and of other items of arbitrary complexity with atomic control. Also in 1986, Drexler co-founded The Foresight Institute (with which he is no longer affiliated) to help increase public awareness and understanding of nanotechnology concepts and implications[2].

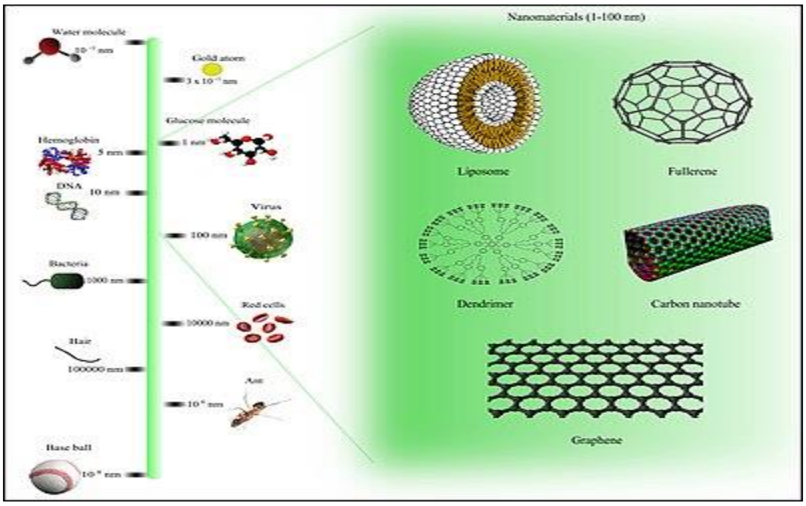

Figure 1: Comparison of nanomaterials sizes

Nanotechnology mainly focuses on the processing of separation, consolidation and deformation of materials by one atom or one molecule. Surface area and Quantum mechanical effects are the important factors in describing properties of matter. The definition of nanotechnology is inclusive of all types of research and technologies that deal with the structure and size as special properties. It is therefore common to see the plural form "nanotechnologies" as well as "nanoscale technologies" to refer to the broad range of research and applications whose common trait is size. One nanometer (nm) is one billionth, or 10^{-9}, of a meter. By comparison, typical carbon–carbon bond lengths, or the spacing between these atoms in a molecule, are in the range 0.12–0.15 nm, and a DNA double-helix has a diameter around 2 nm.

Two main approaches are used in nanotechnology for the synthesis of Nanomaterials. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition.In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control.Areas of physics such as nanoelectronics, nanomechanics, nanophotonics and nanoionics have evolved during the last few decades to provide a basic scientific foundation of nanotechnology.Materials reduced to the nanoscale can show different properties compared to what they exhibit on a macroscale, enabling unique applications. For instance, opaque substances can become transparent (copper); stable materials can turn combustible (aluminium); insoluble materials may become soluble (gold). A material such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these quantum and surface phenomena that matter exhibits at the nanoscale.

Bibliometric analysis of the publications in various disciplines has been published in numerous studies during the previous decade such as; thin film for Solar cell Fabrication(3), Digital Literacy(4), VIT University(5) and Cloud Computing in Libraries(6). In this regard, the study is conducted on the assessment of the currently published research articles in the field of Nanotechnology.

The bibliometric method is a prominent research tool that can systematically represent the nature of specific scientific disciplines by highlighting research hotspots and detecting research trends. The Web of Science (WOS), maintained by Thomson Reuters, is considered one of the main bibliographic sources of information. Our study accumulated extensive bibliometric data on this field from the Web of Science database, between 2014 to 2024, and conducted a scientometric analysis using VOSviewer for analyzing the retrieved data. The leading journals, highly used keywords in the published articles, authors and papers with the highest citations, and relevant regions were all identifed in the scientometric analysis. Our scientometric findings can help academics collaborate on research, form joint ventures, and implement sophisticated technologies for implementing Nanotechnology.

Objectives of the study

1. To examine the growth on Nanotechnology publications in the from 2014 to 2023 using the Web of Science platform.
2. To conduct an in-depth study on year-wise, ranking of journal, ranking of institution, country-wise, keywords, authorship pattern.

Methodology

Data used in this study were obtained from the Web of Science core collection with a search of keyword "Nanotechnology" in terms of a publication source name. The data were obtained on January 8, 2023. Documents published in the first 10 years (from 2014 to 2023). There are analyzed through the parameters of publication output, author keywords, most productive authors, institutes and countries. The data were analyzed with VoS viewer mapping tools were used to study the collaboration behaviour and citation network.

Results and Analysis:

Annual Productivity

Table 1 Figure 2 presents the annual scientific production of Nanotechnology. The numbers of articles published in the period from 2014 to 2023. The research articles are gradually increasing trend in the study period. The study shows that the highest numbers of 2792 research articles are published in the year 2022. The lowest number of 799 research articles is published in the year 2014.

Table 1: Year wise contribution of Nanotechnology

Years	Publication	%
2014	799	4.87
2015	916	5.59
2016	1100	6.71
2017	1220	7.45
2018	1472	8.97
2019	1480	9.03
2020	1869	11.4
2021	2368	14.45
2022	2792	17.03
2023	2377	14.5
	16393	100

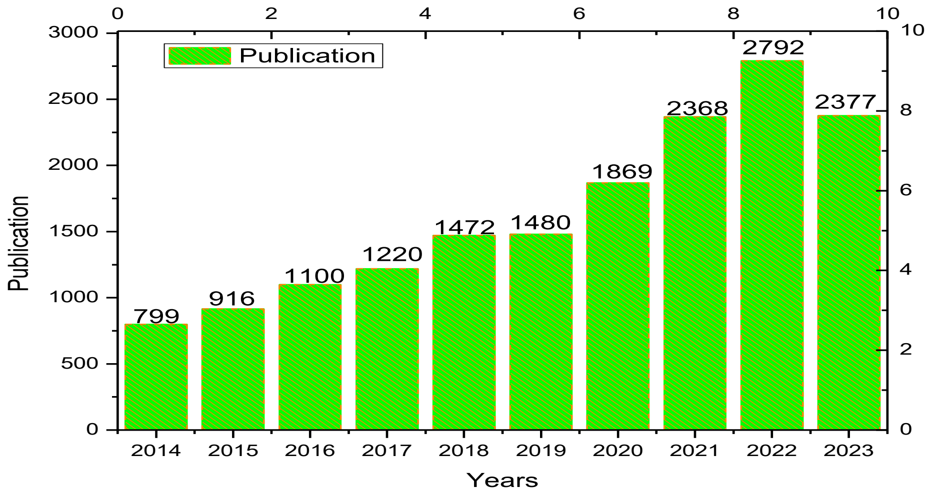

Figure 2: Year wise contribution of Nanotechnology

Co- Authorship Mapping

The VOS viewer visualisation map is shown in figure 3 where an individual circle represents an author and the size of each circle represents the link strength of the author *i.e.*, larger the size of the circle higher is the link strength. The co-authorship links of a given researcher with other researcher can be found out from the links attribute and the link strengths represents the strength of the co-authorship links. The pattern of network connections indicates the presence of a core network. The authors are divided into different clusters. In order to create a clear visualisation map, the authors having at least five publications are taken after that 746 authors with the 34 cluster, 2354 links and 3319 total link strength are connected. Top ten leading authors are Liu, Yang (41 Documents), Zhang, Wei (36 Documents), Wang, Wei (35 Documents), Wang, Yan (29 Documents), Wang, Li and Zhang, Yu (28 Documents each), Li, Wei and Wang, Jun (27 Documents each), Zhang, Lei (26 documents) and Hasanzadeh, Mohammad (25 documents).

Table 2: Leading Authors contribution of Nanotechnology

S.No	Authors	Documents	Citations
1	Liu, Yang	41	661
2	Zhang, Wei	36	624
3	Wang, Wei	35	824
4	Wang, Yan	29	598
5	Wang, Li	28	458
6	Zhang, Yu	28	997
7	Li, Wei	27	352
8	Wang, Jun	27	675
9	Zhang, Lei	26	606
10	Hasanzadeh, Mohammad	25	420

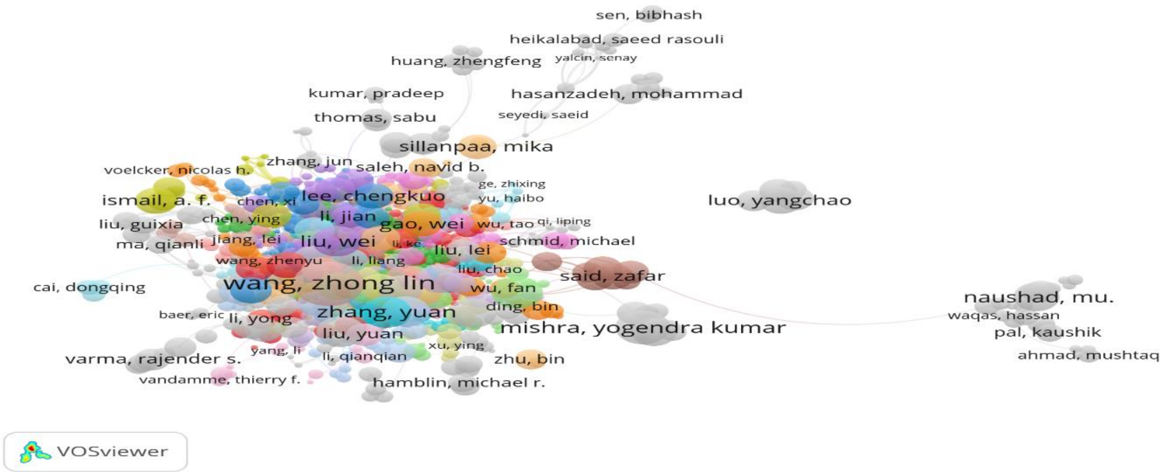

Figure 3: Leading Co-Authorship contribution of Nanotechnology

Authors keywords occurrence

Figure 4 shows that author keywords provide an indication of the prevalence of topics addressed by research. How they co-occur provides a further indication of their mutual relationships. The number of author keywords generated for each period is too large to display the complete vocabulary. Table 3 For the period 2014–2023, Yield is the 1st rank in the keywords with Nanotechnology 468 occurance followed by Nanoparticles, Nanomaterials, Mechanical Properties and Microstructure etc

Table 3: Leading keywords occurrence of nanotechnology

S.No	Keywords	Occurrences
1	Nanotechnology	468
2	Nanoparticles	446
3	Nanomaterials	243
4	Mechanical Properties	203
5	Microstructure	202
6	Drug Delivery	183
7	Adsorption	165
8	Graphene	157
9	3d Printing	140
10	Electrospinning	139

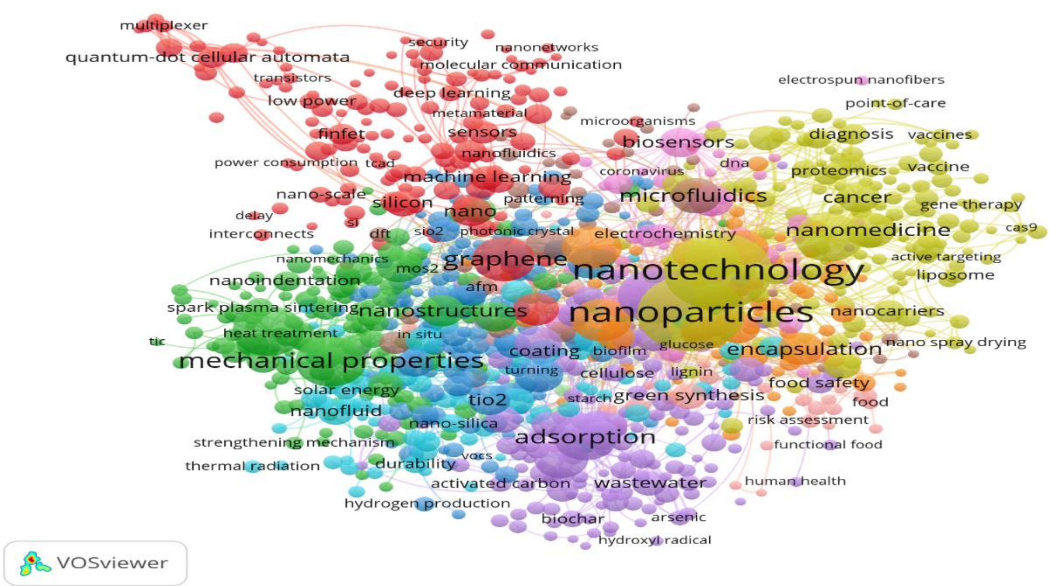

Figure 4: Leading keywords occurrence of nanotechnology

Countries Collaborations

The VOSviewer visualizations for the direct citation relationships between countries for the periods 2014-2023 appear in Figure 4. Clusters were limited to a minimum of five members. Each country appearing in the figure met a minimum productivity threshold of five publications for the time period investigated. However, the smaller the node, the less likely it is that there is a connection with other countries. It was used to identify the most contributing countries in the development of Nanotechnology. As can be observed from Table 4 and Figure 5, Peoples china

(6418 documents) is leading in terms of publications released followed by the USA(2158 documents), India(1607 documents), Iran (904 documents), South Korea (791 documents), England (681 documents), Germany (676 documents), Japan (603 documents), Australia (569 Documents) and Italy (556 documents)occupied the next ranks in the number of publications.

Table 4: Leading countries contribution of nanotechnology

S.No	Countries	Documents	Citations
1	Peoples R China	6418	132249
2	USA	2158	78865
3	India	1607	36898
4	Iran	904	23235
5	South Korea	791	20966
6	England	681	25649
7	Germany	676	20220
8	Japan	603	12970
9	Australia	569	21280
10	Italy	556	18099

Figure 5: Leading countries contribution of nanotechnology

Organisation productivity

Table 5 and Figure 6 represents the information of Institutions in which the articles in the field of Nanotechnology. These were calculated using the VoS Viewer software. Regarding the citation count, The Institutions "Chinese Acad Sci" holds the first rank published 723 research papers. The "Univ Chinese Acad Sci" holds the second rank published 286 research papers. The "Islamic Azad Univ" holds the third rank published 197 research papers. The "Tsinghua Univ" holds the forth rank published 190 research papers. The "Zhejiang Univ" holds the fifth rank published 188 research papers and etc.

Table 5: Leading organisation contribution of nanotechnology

S.No	Organisation	Documents	Citations
1	Chinese Acad Sci	723	16330
2	Univ Chinese Acad Sci	286	5669
3	Islamic Azad Univ	197	5038
4	Tsinghua Univ	190	5264
5	Zhejiang Univ	188	4807
6	Shanghai Jiao Tong Univ	171	3871
7	Harbin Inst Technol	167	4340
8	Xi An Jiao Tong Univ	161	3253
9	Sichuan Univ	131	1990
10	Tianjin Univ	128	3431

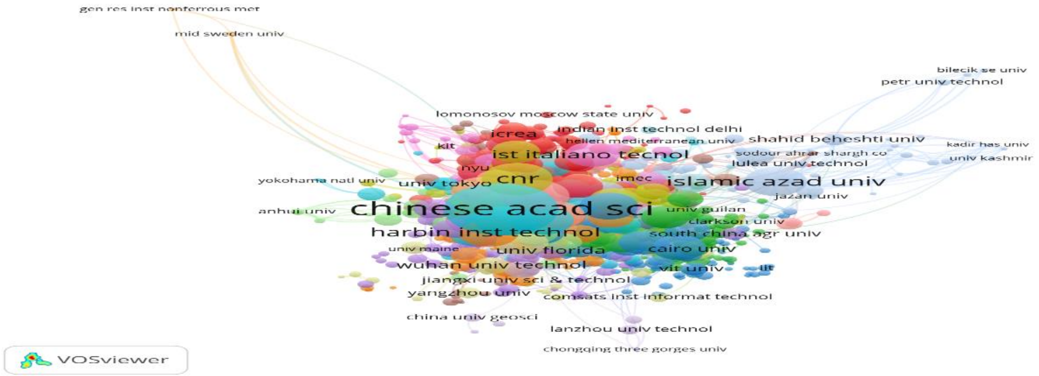

Figure 6: Leading organisation contribution of nanotechnology

Table 6: Leading journals contribution of nanotechnology

S.No	Journals	Documents	Citations
1	Advanced powder technology	287	5469
2	Journal of materials science & technology	272	5581
3	Nanomaterials	196	3149
4	Scientific reports	189	5161
5	Chemical engineering journal	162	6338
6	Rsc advances	151	2701
7	Materials	145	2663
8	Applied surface science	122	1931
9	Nanoscale	121	4497
10	Ceramics international	115	2040

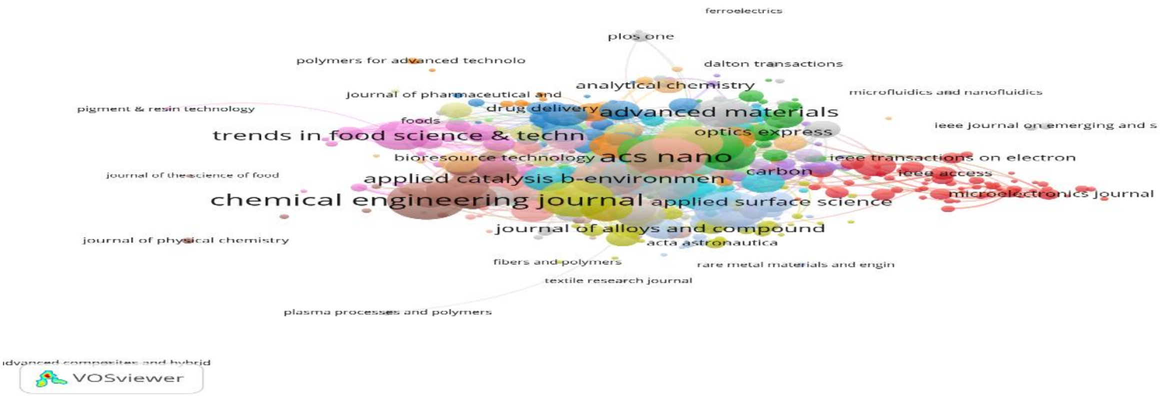

Figure 7: Leading journal contribution of nanotechnology

Journal productivity

Table 6 and Figure 7 represents the information of journals in which the articles in the field of Nanotechnology. These were calculated using the VoS Viewer software. Regarding the citation count, The journal “Advanced powder technology” holds the first rank published 287 research papers. The “Journal of materials science & technology” holds the second rank published 272 research papers. The “Nanomaterials” holds the third rank published 196 research papers. The “Scientific reports” holds the fourth rank published 189 research papers. The “Chemical engineering journal” the fifth rank published 162 research papers.

Conclusion:

The present work explores the characteristics of Nanotechnology literature from 2014 to 2023 based on the database of Web of Science (WoS) and its implication using the scientometric techniques. There is a large quantity of research conducted surrounding Nanotechnology, as shown from the productivity graphs developed with adsorbent technologies leading the way in terms of quantity, in both articles and citations. It was performed to visualize panorama of publications, the most prominent authors, institutions, countries, research categories, and journals. These indicators are intended to facilitate researchers in analysis of existing literature which could improve the research direction for better scientific contribution. Peoples Republic of China and USA are the two biggest contributing countries and India occupied third place on Nanotechnology effluents literature. These indicators are intended to facilitate researchers in analysis of existing literature which could improve the research direction for better scientific contribution.

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NANOPARTICLES: BUILDING BLOCKS OF FUTURE TECHNOLOGIES – AN OVERVIEW

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Abstract:

The utilization of nanoparticles as the building blocks of future technologies represents a paradigm shift in various scientific and technological domains. This overview explores the unique and versatile properties of nanoparticles that position them as fundamental components for shaping the future. At the nanoscale, nanoparticles exhibit distinctive physical, chemical, and biological characteristics, allowing for precise tailoring of their properties. The synthesis methods, both bottom-up and top-down, offer a diverse toolkit for crafting nanoparticles with specific sizes, shapes, and compositions. This abstract delves into the pivotal role of nanoparticles in advancing fields such as medicine, electronics, catalysis, and materials science. The characterization of nanoparticles, a critical aspect of their study, involves intricate analyses of size, composition, structure, surface properties, and morphology. Understanding these characteristics is paramount for harnessing the full potential of nanoparticles in applications ranging from targeted drug delivery and enhanced imaging to improved electronic devices and environmental remediation. Despite their tremendous potential, the abstract also touches upon the ethical and safety considerations associated with nanoparticles. As the building blocks of future technologies, nanoparticles are poised to revolutionize industries, offering innovative solutions and pushing the boundaries of what is achievable in the realms of science and technology.

Introduction:

In the burgeoning landscape of technological innovation, nanoparticles emerge as the microscopic architects of a future redefined by their extraordinary properties. At the heart of this paradigm shift lies the intricate world of nanomaterials, where materials at the nanoscale unveil unique characteristics that transcend the limitations of their bulk counterparts. This overview delves into the realm of nanoparticles, exploring how these minuscule entities become the foundational building blocks propelling future technologies to unprecedented heights. Nanoparticles, typically ranging from 1 to 100 nanometers, boast a realm of properties distinct to their nanoscale dimensions. Their size imparts remarkable surface area-to-volume ratios, unlocking unparalleled reactivity and functionality. The synthesis of nanoparticles involves meticulous methods, encompassing both bottom-up approaches, where nanoscale structures are meticulously constructed, and top-down strategies, involving the precision reduction of larger materials. This nuanced control over size, shape, and composition provides scientists with a versatile palette to engineer nanoparticles tailored for specific applications. As we navigate through the intricacies of nanoparticles, their significance unfolds across diverse domains. From groundbreaking advancements in medicine, where nanoparticles serve as targeted drug delivery vehicles, to the realm of electronics, where their unique electrical and thermal properties promise transformative devices, the influence of nanoparticles spans wide and deep. Catalysis, materials science, and environmental remediation also stand poised for radical transformations through the integration of these microscopic entities.

Yet, the journey into the nanoworld demands an equal commitment to understanding and characterizing these entities. Size analysis, chemical composition assessment, structural insights, and an exploration of surface properties collectively provide the roadmap to unlock the full potential of nanoparticles. This exploration, however, is not without ethical and safety considerations, necessitating a balanced approach as we harness the immense capabilities of nanoparticles. In this pursuit of knowledge and innovation, the world of nanoparticles beckons—a frontier where the fusion of science and technology converges to redefine the boundaries of what is achievable. As we embark on this odyssey, nanoparticles stand poised as the architects, laying the foundation for the future technologies that promise to shape our world in unprecedented ways.

Defining nanoparticle classes

The three main categories of nanoparticles are carbon-based, inorganic, and organic. Nanoparticles, characterized by their extremely small size ranging from 1 to 100 nanometers, exhibit diverse properties and compositions. The three primary categories of nanoparticles are carbon-based, inorganic, and organic, each with distinct characteristics and applications.

Carbon based nanoparticles

Carbon-based nanoparticles are predominantly composed of carbon atoms and manifest in various forms. Fullerenes, for instance, are unique hollow structures resembling spheres or ellipsoids, while carbon nanotubes exhibit cylindrical shapes with exceptional electrical and mechanical properties. Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, showcases remarkable strength, electrical conductivity, and thermal conductivity. These materials find applications in electronics, materials science, and medical fields due to their unique properties.

Organic nanoparticles

Organic nanoparticles consist of carbon-containing compounds, either derived from living organisms or synthesized organic molecules. Examples include liposomes and micelles, which are self-assembling structures formed by amphiphilic molecules. These organic nanoparticles are commonly employed in drug delivery systems, encapsulating and transporting drugs to specific targets. These nanoparticles are biodegradable, non-toxic, and some of them, like micelles and liposomes, have hollow centres that give them the name "nanocapsules" and make them sensitive to electromagnetic radiation like heat and light. Dendrimers, characterized by highly branched structures, find applications in targeted drug delivery and imaging. The versatility of organic nanoparticles makes them valuable in various fields, particularly in the pharmaceutical and biomedical domains.

Inorganic nanoparticles

Inorganic nanoparticles encompass a broad range of materials, excluding carbon, such as metals, metal oxides, and semiconductors. Metal nanoparticles, including gold and silver nanoparticles, possess distinctive optical properties and are utilized in catalysis, imaging, and sensing applications. Metal oxide nanoparticles, like titanium dioxide and iron oxide, play essential roles in medicine, environmental remediation, and energy storage. Semiconducting nanoparticles, such as quantum dots, with tunable electronic properties, are employed in electronics, photonics, and medical imaging.

Metal based nanoparticles

Metal-based nanoparticles, a prominent subset within the realm of nanomaterials, consist predominantly of metallic elements and exhibit unique properties attributed to their nanoscale dimensions. These nanoparticles possess distinctive features that make them highly valuable across scientific, industrial, and medical domains. One key characteristic is the size-dependent behavior of metal nanoparticles, which imparts novel optical, electronic, and catalytic properties compared to their bulk counterparts.

A noteworthy optical phenomenon associated with metal-based nanoparticles is surface plasmon resonance (SPR). This effect is particularly pronounced in materials like gold and silver nanoparticles, contributing to their applications in sensing and imaging. Additionally, the high surface area and reactivity of certain metal nanoparticles, such as palladium and platinum nanoparticles, render them highly effective catalysts in various chemical reactions.

Metal-based nanoparticles come in diverse forms, each tailored to specific applications. Gold nanoparticles, for instance, are well-regarded for their stability, biocompatibility, and unique optical characteristics, making them integral in diagnostics, imaging, and drug delivery in the biomedical field. Silver nanoparticles, celebrated for their antimicrobial properties, find applications in medical contexts such as wound healing and the creation of antibacterial coatings. Iron oxide nanoparticles, while containing both metal and oxygen, are often classified as metal-based and are crucial in magnetic resonance imaging (MRI) and as contrast agents for biomedical imaging.

The applications of metal-based nanoparticles span multiple domains. In medicine, they play a pivotal role in imaging, diagnostics, and targeted drug delivery. Gold and iron oxide nanoparticles, for instance, are utilized in cancer therapy and imaging techniques. Beyond healthcare, metal nanoparticles contribute significantly to catalysis, enhancing the efficiency and selectivity of various chemical processes. Moreover, they play a crucial role in the development of advanced electronic devices, sensors, and conductive inks, leveraging their unique electronic properties.

Metal oxide based

Metal oxide-based nanoparticles represent a significant category within the broader spectrum of nanomaterials, characterized by their composition of metallic elements combined with oxygen. These nanoparticles exhibit distinct properties arising from their nanoscale dimensions, and their versatile nature finds applications across various scientific, industrial, and biomedical fields.

One notable characteristic of metal oxide nanoparticles is their unique electronic and catalytic properties, which make them valuable in diverse applications. Examples of commonly studied metal oxide nanoparticles include titanium dioxide (TiO_2), zinc oxide (ZnO), and iron oxide (Fe_2O_3 or Fe_3O_4). Titanium dioxide nanoparticles, for instance, are known for their photocatalytic activity, finding applications in environmental remediation and self-cleaning surfaces. Zinc oxide nanoparticles are recognized for their semiconducting properties, making them useful in electronics, optoelectronics, and UV-blocking applications. Iron oxide nanoparticles, encompassing both magnetite (Fe_3O_4) and hematite (Fe_2O_3), are renowned for their magnetic properties, contributing to applications in magnetic resonance imaging (MRI) and targeted drug delivery.

The applications of metal oxide nanoparticles extend into the environmental and energy sectors. Titanium dioxide nanoparticles, when exposed to ultraviolet light, exhibit photocatalytic activity, leading to the degradation of organic pollutants in water and air. Zinc oxide nanoparticles find use in solar cells and sensors due to their semiconducting properties. Iron oxide nanoparticles are employed in environmental cleanup efforts, such as the removal of heavy metals from water, owing to their magnetic characteristics that facilitate separation processes.

Biomedical applications also benefit from the unique properties of metal oxide nanoparticles. Iron oxide nanoparticles, in particular, are widely used in magnetic resonance imaging (MRI) as contrast agents for improved imaging quality. Additionally, metal oxide nanoparticles are explored for drug delivery systems, leveraging their biocompatibility and surface functionalization capabilities.

Fullerenes (C60):

Fullerenes, with the prototypical example being C60, represent a fascinating class of carbon-based nanoparticles. These molecules are structured as spherical carbon cages, with the carbon atoms forming a network held together by sp2 hybridization. Comprising 28 to 1500 carbon atoms, fullerenes exhibit a diameter range of up to 8.2 nm for a single layer and 4 to 36 nm for multi-layered configurations. Their unique geometry and properties have led to applications in various fields, including materials science, electronics, and medicine. Fullerenes are particularly renowned for their exceptional stability and ability to encapsulate other molecules, making them valuable in drug delivery systems and nanotechnology.

Graphene:

Graphene is another notable carbon allotrope, characterized by a two-dimensional, hexagonal honeycomb lattice structure formed by carbon atoms. This single layer of carbon atoms arranged in a flat surface typically has a thickness of 1 nm. Graphene has garnered widespread attention due to its extraordinary mechanical, electrical, and thermal properties. Its high electrical conductivity and mechanical strength make it a promising material for applications in electronics, energy storage, and composite materials. Ongoing research explores graphene's potential in various fields, from flexible electronics to advanced sensors.

Carbon Nanotubes (CNT):

Carbon nanotubes (CNT) are nanoscale structures derived from a graphene nanofoil, featuring a honeycomb lattice of carbon atoms. CNTs exhibit diameters as small as 0.7 nm and can be classified into single-walled (SWCNT) or multi-walled (MWCNT) structures. The cylindrical nature of CNTs imparts exceptional mechanical strength, thermal conductivity, and electrical properties. These attributes make carbon nanotubes valuable in applications such as nanoelectronics, composite materials, and even potential applications in medicine, such as drug delivery systems.

Carbon Nanofiber:

Carbon nanofiber (CNF), akin to CNT, is also derived from graphene nanofoils but adopts a distinct three-dimensional structure. Unlike the cylindrical shape of carbon nanotubes, carbon nanofibers are twisted into cone- or cup-shaped configurations. This unique morphology influences their mechanical and surface properties, offering advantages in specific applications. Carbon nanofibers find use in various fields, including aerospace, materials reinforcement, and energy storage, where their structural characteristics contribute to enhanced performance.

Method of synthesis of nanoparticles:

Nanoparticles can be synthesized through a variety of methods, broadly categorized as bottom-up and top-down approaches. The bottom-up methods involve building nanoparticles from smaller components, while top-down methods involve breaking down larger materials into nanoparticles. Each method offers unique advantages and is suited to specific types of nanoparticles and intended applications.

1. ***Bottom-up synthesis methods:***

A) Sol-Gel method: This method involves the transformation of a solution or colloidal system into a solid gel phase, followed by subsequent drying and annealing processes. It is commonly employed for the synthesis of carbon, metal, and metal oxide nanoparticles.

B) Spinning method: Spinning techniques, such as electrospinning, are utilized to create fibers from polymer solutions, resulting in the formation of nanoparticles composed of organic polymers.

C) Chemical Vapour Deposition (CVD): Gaseous reactants undergo chemical reactions to deposit thin films or nanoparticles on a substrate. This method is applicable for generating carbon and metal-based nanoparticles.

D) Pyrolysis: This method involves the decomposition of precursor materials at high temperatures, leading to the formation of nanoparticles. Pyrolysis is commonly employed for synthesizing carbon and metal oxide-based nanoparticles.

E) Biosynthesis: Biological agents, including microorganisms or plant extracts, are employed to facilitate the synthesis of nanoparticles. This method yields a diverse range of nanoparticles, including organic polymers and metal-based nanoparticles.

2. Top-Down Synthesis Methods:

A) Mechanical milling: Mechanical forces are applied to reduce the size of bulk materials, resulting in the formation of nanoparticles. This method is versatile and produces nanoparticles composed of metals, oxides, and polymers.

B) Nanolithography: Utilizing lithographic techniques, patterns are created on a substrate, leading to the formation of metal-based nanoparticles. This method is crucial for precision in nanoparticle fabrication.

C) Laser ablation: Laser irradiation on a target material causes ablation and generates nanoparticles. Laser ablation is effective in producing carbon-based and metal oxide-based nanoparticles.

D) Sputtering: Energetic ions are used to dislodge atoms from a target material, resulting in the formation of metal-based nanoparticles.

E) Thermal decomposition: Precursors undergo decomposition at elevated temperatures, leading to the formation of nanoparticles. This method is commonly used for synthesizing carbon and metal oxide-based nanoparticles.

These diverse synthesis methods provide control over nanoparticle size, shape, and composition, enabling their tailored production for specific applications in fields such as medicine, electronics, catalysis, and materials science. The selection of a particular method depends on the desired properties of the nanoparticles and the intended application.

Properties of nanoparticles:

Nanoparticles, characterized by their extremely small size ranging from 1 to 100 nanometers, exhibit a plethora of unique properties owing to their nanoscale dimensions. One fundamental property is the increased surface area-to-volume ratio compared to bulk materials. This heightened surface area contributes to enhanced reactivity, making nanoparticles highly suitable for catalysis and other surface-dependent processes. Additionally, the quantum effects that emerge at the nanoscale impart distinct optical and electronic properties. Quantum confinement effects influence the band structure of nanoparticles, resulting in size-dependent changes in electronic transitions and optical absorption.

Another critical property is the tunability of nanoparticle properties based on size, shape, and composition. The ability to precisely control these parameters allows researchers to tailor nanoparticles for specific applications. For instance, in medicine, the size and surface chemistry of nanoparticles can be adjusted to optimize drug delivery, cellular uptake, and biocompatibility. In electronics, the unique electrical and magnetic properties of nanoparticles make them valuable for developing advanced materials and devices. The thermal properties of nanoparticles are also noteworthy. Nanoparticles often exhibit enhance thermal conductivity, making them valuable in applications such as heat dissipation in electronics or as contrast agents in thermal imaging. Moreover, the mechanical properties of nanoparticles, including strength and hardness, can differ significantly from their bulk counterparts. These variations in mechanical behavior open avenues for the development of advanced materials with improved mechanical performance. Nanoparticles may display surface plasmon resonance (SPR), a phenomenon particularly observed in metal nanoparticles. SPR influences the absorption and scattering of light, making these nanoparticles useful in applications such as sensors, imaging, and photothermal therapy. In the environmental context, nanoparticles can exhibit unique chemical and physical interactions due to their small size. This can impact their transport, fate, and toxicity in ecosystems. Understanding these properties is crucial for responsible and sustainable deployment of nanoparticles in various applications. Despite the myriad advantages, the small size of nanoparticles can also raise concerns, particularly related to toxicity and potential environmental impacts. Researchers and regulatory bodies carefully investigate the biological and environmental effects of nanoparticles to ensure their safe use.

Nanoparticle characterization:

Nanoparticle characterization is a crucial step in understanding and optimizing the properties of nanomaterials for various applications. It involves a comprehensive assessment of their physical, chemical, and structural attributes, given the unique nature of nanoparticles at the nanoscale. One primary aspect of characterization is size analysis, which is often achieved through techniques such as dynamic light scattering, electron microscopy, or atomic force microscopy. These methods provide insights into the distribution and average size of nanoparticles, allowing researchers to tailor their synthesis processes for specific applications. Chemical composition analysis is another vital dimension of nanoparticle characterization. Techniques such as X-ray photoelectron spectroscopy (XPS) and energy-dispersive X-ray spectroscopy (EDS) offer valuable information about the elemental composition of nanoparticles, aiding in quality control and ensuring the desired properties are achieved.

Structural characterization involves understanding the crystalline or amorphous nature of nanoparticles. X-ray diffraction (XRD) is commonly employed to determine the crystal structure, providing insights into the arrangement of atoms within the nanoparticles. This information is crucial for applications were crystal structure influences material properties, such as catalysis or semiconductors. Surface properties are also extensively characterized as they significantly influence the interaction of nanoparticles with their environment. Techniques like Fourier-transform infrared spectroscopy (FTIR) and surface area analysis methods provide information about surface functional groups, facilitating the design of nanoparticles for specific applications, such as drug delivery or catalysis. Morphological characterization, which involves studying the shape and surface morphology of nanoparticles, is accomplished using electron microscopy techniques such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM). These methods offer high-resolution imaging, allowing researchers to observe individual nanoparticles and evaluate their structural integrity. Zeta potential measurements are employed to assess the surface charge of nanoparticles, influencing their stability and interaction with biological systems. This is particularly relevant in biomedical applications were understanding the behavior of nanoparticles in physiological environments is critical. Real-time or in situ characterization techniques, such as in situ spectroscopy or in situ microscopy, provide a dynamic view of how nanoparticles evolve during synthesis or in various environments, offering valuable insights into their behavior under specific conditions. Overall, nanoparticle characterization is a multidimensional process that combines various techniques to provide a comprehensive understanding of their properties. This knowledge is pivotal for tailoring nanoparticles to meet specific application requirements, ensuring their safety, efficacy, and performance in diverse fields ranging from medicine to materials science.

Conclusion:

In conclusion, the exploration of nanoparticles as the building blocks of future technologies unveils a realm of immense promise and transformative potential. Throughout this overview, we have delved into the unique and intricate properties of nanoparticles, underscoring their role as fundamental entities in the nanoscale landscape. The ability to precisely engineer nanoparticles, whether through bottom-up synthesis methods or top-down strategies, provides a canvas for innovation across a spectrum of scientific disciplines. The impact of nanoparticles extends far beyond their diminutive size, reaching into the realms of medicine, electronics, catalysis, materials science, and environmental remediation. In medicine, the advent of targeted drug delivery systems and enhanced imaging techniques promises revolutionary advancements, offering more effective and personalized healthcare solutions. The domain of electronics witnesses the integration of nanoparticles, leveraging their exceptional electrical and thermal properties to pave the way for novel devices and more efficient technologies. Characterization techniques play a pivotal role in unraveling the complexities of nanoparticles, providing researchers with the tools to understand and fine-tune their properties. The meticulous analysis of size, composition, structure, surface properties, and morphology facilitates the optimization of nanoparticles for specific applications, ensuring their efficacy and safety. However, as we navigate this frontier, ethical considerations and safety concerns must be addressed with diligence. The potential environmental and health impacts of nanoparticles necessitate a responsible approach to their development and application. As nanoparticles continue to emerge as catalysts for innovation, it becomes imperative to strike a balance between progress and safeguarding the well-being of our ecosystems and communities. Nanoparticles represent more than just infinitesimal entities; they embody the convergence of science and technology, reshaping the landscape of possibilities. This exploration, marked by continuous research, ethical considerations, and technological advancements, propels us towards a future where nanoparticles stand as the cornerstone of unprecedented technological progress. As we traverse this trajectory, the synthesis, characterization, and application of nanoparticles underscore their pivotal role in sculpting the future, promising a tapestry woven with innovation, sustainability, and responsible advancement.

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NANOTECHNOLOGY: REVOLUTIONIZING HEALTHCARE THROUGH INNOVATIVE MEDICAL APPLICATIONS

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Abstract:

Nanotechnology, at the intersection of physics, chemistry, and engineering, has emerged as a transformative force with profound implications across various scientific disciplines. This abstract explores the multifaceted applications of nanotechnology, spanning medicine, regenerative sciences, and beyond. In the medical realm, nanotechnology facilitates precision medicine through targeted therapies, diagnostic nanosensors, and nanorobotics. Moreover, it revolutionizes regenerative medicine by providing nanoscale scaffolds and biomaterials, propelling advancements in tissue engineering and stem cell nanotherapy. The abstract concludes by emphasizing the challenges and potential of nanotechnology, underscoring the ongoing quest for safe, effective, and ethical integration into diverse fields.

Keywords: Nanotechnology, Precision Medicine, Targeted Therapies, Nanorobotics, Diagnostic Nanosensors, Regenerative Medicine, Nanoscale Scaffolds, Stem Cell Nanotherapy, Interdisciplinary Collaboration, Challenges, Future Directions.

Introduction:

Nanotechnology, derived from the Greek word "nano" meaning dwarf, involves manipulating matter at the nanoscale—typically at dimensions less than 100 nanometers. At this scale, unique physical, chemical, and biological properties emerge, offering unprecedented opportunities for innovation and advancement across various fields.

Defining nanotechnology:

Nanotechnology encompasses the understanding, manipulation, and application of materials and devices at the nanoscale. It involves working with structures and systems within the range of approximately 1 to 100 nanometers, where the behavior of matter differs significantly from that at the macroscopic or even microscopic level.

Historical roots:

The conceptual roots of nanotechnology can be traced back to a pivotal lecture by physicist Richard Feynman in 1959, titled "There's Plenty of Room at the Bottom." Feynman envisioned the possibility of manipulating individual atoms to create tiny machines and structures. However, it wasn't until the 1980s that the term "nanotechnology" gained prominence.

- **1980s: Birth of nanotechnology:**

The term was coined by Japanese researcher Norio Taniguchi in 1974, but it gained broader recognition with the publication of the book "Engines of Creation" by Eric Drexler in 1986. Drexler's work introduced the concept of molecular nanotechnology, outlining the potential for building complex structures at the molecular level.

- **1990s: Advancements and nanoscale discoveries:**

The 1990s marked significant progress in imaging and manipulating nanoscale materials. The development of the scanning tunneling microscope (STM) allowed scientists to observe and manipulate individual atoms. This decade laid the foundation for understanding nanoscale phenomena and opened avenues for practical applications.

- **2000s: Nanotechnology goes mainstream:**

Nanotechnology transitioned from theoretical discussions to practical applications in the 21st century. Breakthroughs in nanomaterials, nanoelectronics, and nanomedicine captured global attention. Governments and industries began investing heavily in nanotechnology research and development, leading to a proliferation of innovations. [1]

Significance of nanotechnology in medicine

Nanotechnology's integration into medicine has heralded a new era of possibilities, revolutionizing diagnostics, treatment, and overall healthcare. At the nanoscale, materials exhibit unique properties that can be harnessed for targeted and precise interventions. This chapter explores the profound significance of nanotechnology in advancing medical science.[2]

Precision medicine:

One of the key contributions of nanotechnology to medicine is its role in precision medicine. Nanoscale materials enable the design of drug delivery systems that can target specific cells or tissues with unparalleled precision. This targeted approach minimizes side effects and enhances the efficacy of therapeutic interventions.

Improved drug delivery:

Nanoparticles, liposomes, and other nanocarriers serve as advanced drug delivery vehicles. These carriers protect drugs from degradation, enable controlled release, and enhance the bioavailability of therapeutic agents. The result is more effective treatments for various diseases, including cancer, where nanotechnology has shown remarkable success in delivering chemotherapy directly to cancer cells.

Diagnostic advancements:

Nanotechnology has transformed diagnostic capabilities, allowing for early disease detection and personalized diagnostics. Nanosensors and nanoprobes can detect molecular changes indicative of diseases at their nascent stages. This early detection facilitates prompt and targeted interventions, improving patient outcomes.

Therapeutic innovations in cancer:

In oncology, nanotechnology has emerged as a powerful ally. Nanoparticles can be engineered to selectively target cancer cells, delivering therapeutic payloads directly to the site of the disease. This targeted approach minimizes damage to healthy tissues and enhances the effectiveness of treatments, leading to improved survival rates and reduced side effects.

Regenerative medicine and tissue engineering:

Nanotechnology plays a pivotal role in regenerative medicine by facilitating the development of nanomaterials for tissue engineering. Nanoscale scaffolds and biomaterials support cell growth and regeneration, offering new possibilities for organ and tissue transplantation. This holds potential for addressing the critical shortage of donor organs.

Nanotechnology for neurological disorders:

In the realm of neuroscience, nanotechnology is contributing to the development of innovative therapies for neurological disorders. Nanoparticles can cross the blood-brain barrier, allowing for targeted drug delivery to treat conditions such as Alzheimer's and Parkinson's disease.

Nanoparticles in drug delivery:

The utilization of nanoparticles in drug delivery has emerged as a groundbreaking approach, offering enhanced therapeutic outcomes and reduced side effects. Nanoparticles, with their unique properties at the nanoscale, enable precise targeting, controlled release, and improved bioavailability of therapeutic agents. [3]

Advantages of nanoparticles in drug delivery:

1. **Targeted delivery:** Nanoparticles can be engineered to target specific cells or tissues, delivering drugs directly to the site of action.
2. **Enhanced bioavailability:** The nanoscale size and surface properties of nanoparticles improve the solubility and stability of drugs, enhancing their absorption and bioavailability.

3. **Controlled release:** Nanocarriers enable controlled and sustained release of drugs, prolonging their therapeutic effect and reducing the frequency of administration.
4. **Protection of drugs:** Nanoparticles provide a protective shield for drugs, preventing their degradation and ensuring their stability in various biological environments.

Types of nanoparticles in drug delivery:

1. **Liposomes:** Spherical vesicles composed of lipid bilayers, liposomes encapsulate drugs and can be designed to target specific tissues.
2. **Polymeric nanoparticles:** Particles made from biodegradable polymers can encapsulate a variety of drugs and release them in a controlled manner.
3. **Nanomicelles:** Self-assembled structures formed by amphiphilic molecules that encapsulate hydrophobic drugs, improving their solubility.
4. **Dendrimers:** Highly branched molecules with well-defined structures, dendrimers can carry drugs in their void spaces.
5. **Nanoparticle-drug conjugates:** Covalent attachment of drugs to nanoparticles for targeted delivery and controlled release.

Applications of nanoparticles in drug delivery:

1. **Cancer treatment:** Nanoparticles have shown significant success in delivering chemotherapy directly to cancer cells, minimizing damage to healthy tissues.
2. **Infectious diseases:** Targeted drug delivery using nanoparticles holds promise for treating infections more effectively with reduced side effects.
3. **Neurological disorders:** Nanoparticles can cross the blood-brain barrier, enabling targeted drug delivery for neurological conditions.
4. **Chronic diseases:** Nanoparticles offer controlled release for sustained therapeutic effects, making them suitable for managing chronic conditions.

Nanomedicine for cancer treatment:

Nanomedicine, the application of nanotechnology in medicine, has emerged as a revolutionary approach in the battle against cancer. Harnessing the unique properties of nanoparticles, nanomedicine offers innovative solutions for targeted drug delivery, early detection, and personalized treatment strategies.

Targeted drug delivery: One of the hallmark contributions of nanomedicine to cancer treatment is the development of targeted drug delivery systems. Nanoparticles, such as liposomes and polymeric carriers, can be designed to selectively accumulate in tumor tissues, delivering therapeutic payloads directly to cancer cells. This targeted approach minimizes damage to healthy tissues, enhances drug efficacy, and reduces systemic side effects associated with traditional chemotherapy.

Nanoparticles in chemotherapy: Nanoparticles play a pivotal role in improving the effectiveness of chemotherapy. By encapsulating chemotherapeutic agents, nanoparticles protect drugs from premature degradation, allow controlled release, and facilitate sustained drug exposure to cancer cells. This not only enhances the therapeutic impact but also contributes to minimizing the development of drug resistance.

Photothermal and photodynamic nanotherapies: Nanomedicine explores innovative therapies, such as photothermal and photodynamic therapies, that utilize nanoparticles to selectively destroy cancer cells. Gold nanoparticles, for example, can absorb light and convert it into heat, effectively ablating cancer cells. Similarly, photosensitizer-loaded nanoparticles enable targeted destruction of cancer cells through the generation of reactive oxygen species.

Early detection and imaging: Nanotechnology has revolutionized cancer diagnostics by enabling early detection and accurate imaging. Nanoparticles serve as contrast agents in various imaging modalities, including magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET). These contrast agents enhance the visibility of tumors, allowing for precise localization and staging.

Personalized nanomedicine: Nanotechnology facilitates the development of personalized cancer therapies. Nanoparticles can be engineered to carry specific drugs based on the genetic and molecular characteristics of an individual's tumor. This personalized approach tailors treatment strategies to the unique biology of each patient, maximizing therapeutic efficacy while minimizing adverse effects. [4]

Diagnostic nanosensors:

Diagnostic nanosensors represent a cutting-edge application of nanotechnology in the field of healthcare, offering unprecedented capabilities for the detection and monitoring of diseases at the molecular level. These nanoscale sensors provide sensitive, rapid, and specific diagnostic information, contributing to early disease detection and personalized medicine.

Principles of diagnostic nanosensors: Nanosensors function based on the principles of detecting specific biomolecules or changes in physiological parameters associated with diseases. They are typically composed of nanomaterials with unique properties, such as high surface area and enhanced reactivity, enabling the precise recognition and quantification of target molecules. [5]

Types of diagnostic nanosensors:

1. **Biosensors:** Nanoscale devices that combine a biological recognition element (such as enzymes or antibodies) with a transducer to convert the recognition event into a measurable signal. Biosensors are versatile and can be tailored for detecting various biomarkers.
2. **Quantum dot sensors:** Semiconductor nanoparticles with size-tunable optical properties. Quantum dots can be engineered to emit specific wavelengths of light upon interaction with target molecules, allowing for highly sensitive and multiplexed detection.
3. **Nanowire sensors:** Extremely thin semiconductor structures with high sensitivity to changes in electrical conductance. Functionalized nanowires can detect specific molecules, offering potential applications in point-of-care diagnostics.
4. **Magnetic nanoparticle sensors:** Nanoparticles with magnetic properties can be used in sensor platforms. Changes in magnetic properties, induced by target molecules, are detected and translated into diagnostic information.

Applications of diagnostic nanosensors:

1. **Cancer diagnostics:** Nanosensors enable the detection of cancer-specific biomarkers, allowing for early diagnosis and monitoring of treatment responses. They contribute to liquid biopsy approaches, offering minimally invasive alternatives to traditional diagnostic methods.
2. **Infectious disease detection:** Nanosensors play a crucial role in identifying specific pathogens or antigens associated with infectious diseases. They facilitate rapid and accurate detection in point-of-care settings.
3. **Metabolic and cardiovascular monitoring:** Nanosensors can monitor specific metabolites or biomarkers related to metabolic disorders and cardiovascular diseases. Continuous monitoring enables real-time health assessments.
4. **Environmental and food safety:** Nanosensors are employed to detect contaminants or pathogens in environmental samples and food products, ensuring safety and quality.

Nanotechnology in regenerative medicine:

Nanotechnology has ushered in a new era for regenerative medicine by providing innovative tools and materials at the nanoscale, offering promising solutions for tissue engineering, organ transplantation, and overall regeneration of damaged or degenerated tissues. This intersection of nanotechnology and regenerative medicine holds the potential to revolutionize medical treatments and address the challenges associated with organ shortages and chronic tissue disorders.[6]

Nanoscale scaffolds and biomaterials: Central to the progress in regenerative medicine is the development of nanoscale scaffolds and biomaterials. These structures, often engineered from biocompatible polymers or nanocomposites, mimic the natural extracellular matrix (ECM) and provide a supportive environment for cell growth, differentiation, and tissue regeneration. Nanoscale features of these scaffolds influence cellular behavior and can be tailored for specific tissue types.

Stem cell nanotherapy: Nanotechnology plays a pivotal role in enhancing the therapeutic potential of stem cells for regenerative purposes. Nanoparticles can be designed to deliver stem cells to target tissues with precision, promoting their engraftment and differentiation. This approach holds great promise for treating conditions such as cardiovascular diseases, neurodegenerative disorders, and musculoskeletal injuries.

Nanoparticles for drug delivery in regenerative medicine: In regenerative medicine, nanotechnology contributes to controlled drug delivery systems, ensuring the sustained release of bioactive molecules essential for tissue regeneration. Nanoparticles can encapsulate growth factors, cytokines, or other signaling molecules, providing a controlled and localized delivery that enhances tissue healing and regeneration.

Nanotechnology in organ transplantation: Addressing the critical shortage of donor organs, nanotechnology offers solutions for organ transplantation. Nanomaterials can be used to improve the preservation of donor organs, reduce immune rejection, and enhance the success of transplantation procedures. This approach has the potential to increase the availability of organs for transplantation and improve patient outcomes.

Applications in cartilage and bone regeneration: Nanotechnology is making significant strides in the regeneration of cartilage and bone tissues. Nanomaterials can mimic the structural and mechanical properties of native tissues, promoting the formation of functional bone and cartilage. This is particularly relevant for conditions such as osteoarthritis and bone defects.

Targeted therapies and precision medicine:

The integration of targeted therapies and precision medicine represents a paradigm shift in healthcare, leveraging advancements in molecular biology and nanotechnology to tailor medical treatments to the unique characteristics of individual patients. This approach holds the promise of enhancing therapeutic outcomes while minimizing adverse effects, marking a significant departure from traditional one-size-fits-all treatments. [7]

Principles of precision medicine: Precision medicine, also known as personalized medicine, revolves around the identification of genetic, molecular, and environmental factors that contribute to an individual's health and disease. This comprehensive understanding enables healthcare professionals to customize treatment plans, optimizing efficacy and minimizing side effects.

Targeted therapies: Targeted therapies are a cornerstone of precision medicine, focusing on specific molecules involved in the growth, progression, and survival of cancer cells or other diseased tissues. Unlike conventional chemotherapy, which may affect both healthy and cancerous cells, targeted therapies precisely interfere with the aberrant pathways or proteins that drive disease, resulting in more selective and effective treatments.

Key components of targeted therapies:

1. **Molecular biomarkers:** Identifying specific genetic mutations, protein expressions, or other molecular characteristics that guide treatment decisions.
2. **Monoclonal antibodies:** Engineered antibodies designed to target specific proteins on the surface of cancer cells, blocking signaling pathways or triggering immune responses against the cells.
3. **Small molecule inhibitors:** Drugs that interfere with specific enzymes or signaling molecules involved in the growth and survival of cancer cells.
4. **Immunotherapies:** Activating the patient's immune system to recognize and destroy cancer cells, often by targeting immune checkpoints or using genetically modified immune cells.

Applications in cancer treatment: Precision medicine has particularly transformed the landscape of cancer treatment. Targeted therapies allow oncologists to tailor interventions based on the genetic makeup of a patient's tumor. This approach has led to improved response rates and prolonged survival in various malignancies, ranging from breast and lung cancer to melanoma and leukemia.

Nanorobotics in medicine:

Nanorobots are typically constructed from nanoscale materials, such as nanotubes or nanoparticles, and may incorporate molecular-scale sensors and actuators. These devices are engineered to perform specific functions at the cellular or molecular level, guided by external control mechanisms or autonomous programming. [8]

Applications in medicine:

1. **Targeted drug delivery:**
   - Nanorobots can be designed to transport and deliver therapeutic agents directly to diseased cells or tissues, minimizing side effects and increasing the effectiveness of treatments. This targeted drug delivery approach is especially promising in cancer treatment.

2. **Diagnostics and imaging:**
   - Nanorobots equipped with advanced sensors can navigate the bloodstream or other bodily fluids to detect molecular markers indicative of diseases. Additionally, they can enhance imaging techniques, providing real-time and high-resolution views of specific areas within the body.
3. **Surgery and tissue repair:**
   - Nanorobots have the potential to perform precise surgical procedures at the cellular or molecular level. They can be used for tasks such as tissue repair, removal of abnormal cells, or even the assembly of nanoscale structures for regenerative medicine.
4. **Monitoring and feedback:**
   - Nanorobots can continuously monitor physiological parameters and provide real-time feedback to healthcare professionals. This capability allows for proactive interventions and personalized adjustments to treatment plans.
5. **Nanorobotics in the bloodstream:**
   - Nanorobots designed for navigation within the bloodstream could target and remove blood clots, deliver drugs directly to specific locations, or perform tasks like cleaning arterial plaques.

Nanotechnology for neurological disorders:

Nanotechnology is emerging as a transformative force in the realm of neurological disorders, offering innovative approaches for diagnosis, drug delivery, and therapeutic interventions. The unique properties of nanomaterials allow for precise targeting and manipulation at the molecular and cellular levels, providing new avenues for understanding and treating complex neurological conditions. [9]

Blood-brain barrier penetration: One of the significant challenges in treating neurological disorders is the blood-brain barrier (BBB), a protective barrier that restricts the passage of many therapeutic agents into the brain. Nanotechnology offers solutions by providing nanocarriers that can bypass or traverse the BBB, allowing for targeted drug delivery to specific regions of the brain affected by disorders such as Alzheimer's, Parkinson's, or brain tumors.

Nanoparticles in Alzheimer's and Parkinson's disease: Nanoparticles play a crucial role in the treatment of neurodegenerative diseases, such as Alzheimer's and Parkinson's. They can be designed to carry drugs that target the underlying pathological processes, including the clearance of amyloid-beta plaques in Alzheimer's or the modulation of dopamine levels in Parkinson's. Nanotechnology enhances drug bioavailability and ensures controlled release, improving therapeutic outcomes.

Therapeutic nanomaterials for neurological disorders: Various nanomaterials, including nanoparticles and nanotubes, hold promise for therapeutic interventions in neurological disorders. These materials can be engineered to interact with neural cells, promote neuroregeneration, or deliver neuroprotective agents. Additionally, nanomaterials may serve as platforms for gene therapy, enabling the introduction of therapeutic genes to address genetic components of neurological disorders.

Nanosensors for early detection: Nanosensors play a crucial role in the early detection and monitoring of neurological disorders. These sensors can detect specific biomarkers associated with diseases, providing valuable insights into disease progression and enabling timely interventions. Nanoscale imaging technologies, when integrated with nanosensors, enhance the resolution and accuracy of diagnostic procedures.

Neuromodulation and neural interfaces: Nanotechnology is contributing to the development of neuromodulation devices and neural interfaces. Nanoelectrodes can be used to stimulate or record neural activity with high precision, offering potential therapeutic solutions for conditions like epilepsy or providing advanced interfaces for brain-machine interfaces in conditions of paralysis.

Conclusion:

The integration of nanotechnology into various fields, from medicine to regenerative sciences and beyond, represents a transformative leap in scientific and technological progress. The unique properties of nanomaterials and nanodevices have paved the way for groundbreaking innovations with far-reaching implications. In medicine, nanotechnology has ushered in a new era of precision, offering targeted therapies, personalized treatments, and innovative diagnostic tools. The development of nanorobots promises minimally invasive interventions, while nanosensors enable early detection and monitoring of diseases at the molecular level. Particularly in the realm of neurological disorders, nanotechnology provides hope for novel therapeutic strategies and enhanced diagnostics, addressing challenges that have long eluded conventional approaches.

Regenerative medicine benefits from nanotechnology's ability to engineer nanoscale scaffolds and biomaterials, fostering tissue repair and regeneration. Stem cell nanotherapy, guided by nanoscale precision, holds promise for treating a range of conditions, from cardiovascular diseases to musculoskeletal injuries. Despite these tremendous advancements, challenges persist, including concerns about biocompatibility, toxicity, and ethical considerations. Ongoing research is essential to address these challenges, refine nanomaterial designs, and ensure the safety and efficacy of nanotechnological applications.

Looking forward, the future of nanotechnology appears promising. Continued interdisciplinary collaboration, incorporating fields such as artificial intelligence and materials science, is expected to push the boundaries of what is achievable. As we stand at the intersection of nanotechnology and numerous scientific domains, the potential for revolutionary breakthroughs in healthcare, energy, and beyond is both exciting and inspiring. Nanotechnology's journey from concept to reality continues to shape our understanding of the world and holds the key to addressing some of humanity's most pressing challenges in the years to come.

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NANOTECHNOLOGY IN PHARMACY: REVOLUTIONIZING DRUG DELIVERY AND BEYOND

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Abstract:

Nanotechnology has ushered in a transformative era in pharmacy, revolutionizing drug delivery, diagnostics, and therapeutics by operating at the nanoscale (1 to 100 nanometers). This precise control over material manipulation has given rise to nanoscale drug delivery systems, allowing for the efficient administration of pharmaceutical agents. Notably, the design and synthesis of nanoparticles, encompassing liposomes, micelles, and polymeric nanoparticles, have significantly enhanced drug delivery. These nanoparticles offer advantages such as controlled release, targeted delivery, and improved drug encapsulation, leading to enhanced pharmacokinetics and therapeutic efficacy, thereby minimizing side effects and the need for frequent dosing. In cancer therapy, nanotechnology plays a pivotal role in precision medicine, facilitating selective targeting of cancer cells and amplifying the therapeutic index of anticancer agents. The incorporation of nanotechnology into pharmacy has also accelerated the advent of personalized medicine, tailoring drug delivery systems based on individual patient profiles. Alongside addressing challenges beyond drug delivery, including nanodiagnostics, neuropharmacology, wound healing, and veterinary pharmacy, researchers are delving deeper into nanoscale interactions, paving the way for a future of more targeted, efficient, and personalized pharmaceutical interventions.

Keywords: Nanotechnology, Pharmacy, Medicine, Future

Introduction:

Nanotechnology has revolutionized the field of pharmacy by providing innovative solutions to longstanding challenges in drug delivery, diagnostics, and therapeutics. At the core of this multidisciplinary science is the ability to manipulate and engineer materials at the nanoscale, typically at dimensions ranging from 1 to 100 nanometers. This unprecedented control over matter at such minute levels has paved the way for the development of nanoscale drug delivery systems, enabling more efficient and targeted administration of pharmaceutical agents.

One of the key contributions of nanotechnology in pharmacy is the design and synthesis of nanoparticles for drug delivery. Nanoparticles, such as liposomes, micelles, and polymeric nanoparticles, offer unique advantages in terms of drug encapsulation, controlled release, and targeted delivery to specific tissues or cells. This capability has significantly improved the pharmacokinetics and therapeutic efficacy of various drugs, while minimizing side effects and reducing the need for frequent dosing. In the realm of cancer therapy, nanotechnology has emerged as a powerful tool for precision medicine. Nanoparticle-based drug delivery systems enable the selective targeting of cancer cells, enhancing the therapeutic index of anticancer agents. The ability to encapsulate chemotherapeutic drugs within nanoparticles allows for the delivery of high concentrations directly to the tumor site, minimizing damage to healthy tissues and mitigating systemic toxicity. Nanotechnology has also found applications in diagnostics, offering highly sensitive and specific tools for disease detection. Nanoparticles can be engineered to serve as contrast agents for imaging techniques, as well as components of biosensors for rapid and accurate diagnosis. This convergence of nanotechnology and diagnostics has paved the way for early detection of diseases, leading to more effective therapeutic interventions and improved patient outcomes.

The advent of personalized medicine has been further facilitated by nanotechnology, allowing for the customization of drug delivery systems based on individual patient profiles. Tailoring pharmaceutical interventions to the specific needs of patients not only enhances therapeutic outcomes but also minimizes adverse reactions. Nanotechnology's role in pharmacogenomics, the study of how genetic factors influence drug responses, has opened new avenues for optimizing drug efficacy and safety. As nanotechnology continues to evolve, it addresses challenges beyond drug delivery, spanning areas such as nanodiagnostics, neuropharmacology, wound healing, and veterinary pharmacy. However, alongside the remarkable advancements, researchers and practitioners must also navigate concerns related to Nano toxicology and regulatory aspects. Ensuring the safety of nanomaterials in pharmaceutical applications and establishing standardized guidelines are essential steps to realizing the full potential of nanotechnology in pharmacy.

In conclusion, the integration of nanotechnology in pharmacy represents a paradigm shift, offering unprecedented opportunities for enhancing drug delivery, diagnostics, and therapeutic strategies. As researchers delve deeper into the intricacies of nanoscale interactions, the future holds the promise of more targeted, efficient, and personalized approaches to pharmaceutical interventions [1].

Contribution of Nanotechnology in the field of pharmacy

Nanotechnology has made significant contributions to the field of pharmacy, offering innovative solutions for drug delivery, diagnostics, and therapeutics. Here are several research and review topics related to nanotechnology in pharmacy:

- **Nanoparticle drug delivery systems:**

  Design and development of nanoparticles for drug delivery.

  Controlled release systems for sustained drug release.

- **Targeted drug delivery using nanoparticles.**

  1. Liposomes and nanomicelles:

  Applications of liposomes and nanomicelles in drug delivery.

  Liposomal and micellar formulations for improving drug solubility.

  2. Nanoparticles for cancer therapy:

  Nanoparticle-based approaches for cancer diagnosis and treatment.

  Targeted drug delivery to cancer cells using nanoparticles.

  3. Nano formulations for antibiotics:

  Improving the efficacy and reducing side effects of antibiotics with nanotechnology.

  Nanoparticle-based antibiotic delivery systems.

  4. Nanotechnology in vaccine delivery:

  Development of Nano vaccines for infectious diseases.

  Enhanced vaccine stability and delivery using nanoparticles [2].

  5. Nanoparticles for gene delivery:

  Nano carriers for gene therapy applications.

  Overcoming challenges in gene delivery using nanotechnology.

- **Nanodiagnostics:**

  Nanoparticle-based diagnostic tools for disease detection.

  Biosensors and imaging techniques at the nanoscale.

- **Personalized medicine and nanotechnology:**

  Tailoring drug delivery systems for individual patient needs.

  Nanotechnology applications in pharmacogenomics [3].

- **Nano toxicology in pharmacy:**

  Assessing the safety of nanomaterials in pharmaceutical applications.

  Strategies to mitigate potential toxicity of nanoparticles.

- **Nanotechnology for neuropharmacology:**

  Crossing the blood-brain barrier using Nano carriers.

  Nanoparticle-based therapies for neurological disorders.

- **Nanomaterials for wound healing:**

  Applications of nanotechnology in wound dressings and tissue regeneration.

  Controlled drug release for enhanced wound healing.

- **Nanoparticles in pulmonary drug delivery:**

  Inhalable nanoparticles for respiratory drug delivery.

  Targeted therapy for lung diseases using nanotechnology [4].

- **Biosafety and regulatory aspects:**

  Regulatory challenges and considerations in Nano pharmaceutical development.

  Standardization and guidelines for Nano medicine.

- **Nanotechnology in drug formulation:**

  Nanoscale formulations for improving drug stability and bioavailability.

  Combination therapies using nanotechnology.

- **Nanotechnology in veterinary pharmacy:**

  Applications of nanotechnology in veterinary medicine.

- **Nano formulations for animal health:**

Choosing a specific area within nanotechnology in pharmacy will allow for a more focused and detailed research or review. Additionally, considering the practical implications and potential clinical applications of nanotechnology in pharmacy is crucial for advancing the field [5].

Applications of nanotechnology in pharmacy

1. Utilizing nanoscale carriers (liposomes, micelles, nanoparticles) for drug delivery, enhancing drug solubility, stability, and bioavailability.
2. Precision delivery of drugs to specific cells, tissues, or organs, minimizing systemic side effects and improving therapeutic efficacy.
3. Nanoparticles for targeted and localized delivery of anticancer agents, improving drug accumulation in tumors while sparing healthy tissues.
4. Liposomes and micelles as carriers for hydrophobic drugs, improving drug solubility and enhancing therapeutic outcomes.
5. Nano carriers for efficient and targeted gene delivery, advancing gene therapy for various diseases.
6. Customizing drug delivery systems based on individual patient profiles, tailoring pharmaceutical interventions for improved efficacy and safety.
7. Nanoparticles for sensitive and specific disease detection, Nano biosensors, and imaging agents for diagnostic purposes.

8. Crossing the blood-brain barrier with Nano carriers, nanoparticle-based therapies for neurological disorders.
9. Enhancing the effectiveness of antibiotics using nanotechnology, combating antibiotic resistance through targeted delivery.
10. Nanoscale vaccine formulations for improved efficacy, enhancing vaccine stability and targeted delivery [6].
11. Inhalable nanoparticles for targeted respiratory drug delivery, treatment of lung diseases using nanotechnology.
12. Nanomaterials for advanced wound dressings, controlled drug release for accelerated tissue regeneration.
13. Assessing the safety of nanomaterials in pharmaceutical applications, addressing regulatory challenges, and ensuring compliance.
14. Applications of nanotechnology in veterinary medicine, Nano formulations for improving animal health.
15. Nanoparticles for pollution sensing and remediation, minimizing the environmental impact of pharmaceuticals.
16. These applications highlight the versatility and potential impact of nanotechnology in advancing various aspects of pharmacy, from drug delivery to diagnostics and beyond. Researchers continue to explore and refine these applications to address current challenges in healthcare and pharmaceutical sciences [7,8].

Challenges related to nanotechnology

Some nanomaterials may have unknown or adverse effects on biological systems. Long-term toxicity studies are often limited, raising concerns about their impact on human health.

- Regulatory challenges: Lack of standardized regulations for Nano pharmaceuticals. Difficulty in assessing and managing potential risks, leading to regulatory uncertainty.
- Complex manufacturing processes: Nanoparticle production can be complex and costly. Difficulty in scaling up manufacturing processes for commercial production.
- Particle stability issues: Nanoparticles may agglomerate or undergo changes in size, affecting their stability. Stability challenges may impact the consistency of drug delivery systems [9].
- Limited understanding of fate and transport: Insufficient knowledge about the fate of nanoparticles in the body. Uncertainties regarding their distribution, accumulation, and clearance from the system.
- Immunological reactions: Nanoparticles may trigger immune responses. Immunogenicity can impact the safety and efficacy of Nano pharmaceuticals.

- Ethical concerns: Ethical issues related to the use of nanotechnology in medicine. Concerns about unintended consequences and the potential for misuse.
- Environmental impact: Disposal of nanomaterials may pose environmental challenges. Potential accumulation of nanoparticles in ecosystems with unknown consequences.
- Cost considerations: Development and production costs for nanopharmaceuticals can be high. Economic factors may limit widespread accessibility to these advanced technologies [10].
- Limited standardization: Lack of standardized testing methods for characterizing nanomaterials. Difficulty in comparing and evaluating different Nano pharmaceuticals.
- Intellectual property issues: Complex nature of nanotechnology may lead to intellectual property disputes. Challenges in establishing clear ownership and patent rights.
- Public perception and acceptance: Limited understanding of nanotechnology among the public. Concerns about safety and ethical implications may impact acceptance.
- Challenges in targeting specific cells: Achieving precise targeting can be challenging. Off-target effects may limit the effectiveness of targeted drug delivery.
- Nanoparticle interactions with biological systems: Unpredictable interactions with biomolecules. Potential alterations in the pharmacokinetics and pharmacodynamics of drugs.
- Difficulty in quality control: Ensuring consistent quality in the production of Nano pharmaceuticals.

Challenges in maintaining reproducibility and standardization. While nanotechnology holds great promise in pharmacy, addressing these disadvantages is crucial for ensuring the safe and effective integration of nanomaterials into pharmaceutical applications. Ongoing research and regulatory efforts aim to overcome these challenges and optimize the benefits of nanotechnology in healthcare [11-12].

Future perspectives and conclusion:

As nanotechnology continues to advance, the future of pharmacy holds exciting prospects for innovative drug delivery, diagnostics, and therapeutic strategies. The ability to manipulate materials at the nanoscale opens doors to more targeted, efficient, and personalized approaches in pharmaceutical interventions.

In conclusion, the integration of nanotechnology in pharmacy represents a paradigm shift, offering unprecedented opportunities for enhancing drug delivery, diagnostics, and therapeutic strategies. Researchers, while navigating challenges related to Nano toxicology and regulatory aspects, are paving the way for a future where pharmaceutical interventions are tailored to individual patient profiles, minimizing adverse reactions, and optimizing therapeutic outcomes.

As we delve deeper into the intricacies of nanoscale interactions, the promise of more effective and personalized pharmaceutical approaches becomes increasingly tangible.

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NUTRITIONAL, PHARMACOLOGICAL PROPERTIES AND VALUE ADDED PRODUCTS FROM PALMYRA PALM (*BORASSUS FLABELLIFER L.*) FOR POTENTIAL USE AS FOOD SOURCE AND ITS APPLICATION IN NANOTECHNOLOGY

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Abstract:

The palmyra palm is vital to both animal and human health. Originally from tropical Africa, *Borassus flabellifer* L, also referred to as Palmyra palm, is now grown all throughout India. Traditionally the various plant parts, including the fruit, seeds, roots, and leaves, have historically been used to treat a variety of human ailments. For thatching, mats, baskets, and fans, leaves are utilized. Investigations were conducted on the analgesic and antipyretic properties, anti-inflammatory activity, haematological, biochemical and immunosuppressive properties of *B. flabellifer* flowers. Plants with antihelminthic and diuretic activities are employed for their therapeutic qualities. The sap of *B. flabellifer* has been used as a sweetener for diabetic patients, and the fruit pulp has been employed in traditional cuisines. There are three broad categories into which the applications of the plant can be classified: non-edible, edible, and value-added. The field of nanotechnology is one that is influencing every aspect of human life and leaving its mark on scientific fields daily. The green synthesis of many types of nanomaterials such as gold, silver, zinc-oxide NPs etc. and diverse its applications towards to electrical, optical, biological, and other properties. Eco-friendly metal oxide nanoparticles made from plant extracts are used in catalysis, cosmetics, biosensing, and antibacterial activities against various bacterial infections, particularly in the field of mecicine.

Keywords: *Borassus flabellifer*, Palmyra palm, Green synthesis, Nanotechnology, Metal oxide Nanoparticles

Introduction:

The palmyra palm tree, also known as the *Borassus flabellifer* L., is a dioecious plant that is a member of the Arecaceae family. The Greek words "Borassus" (meaning fruit with a leather covering) and "flabellifer" (meaning fan-bearer) are the source of the *Borassus flabellifer*. Although it originated in tropical Africa, *Borassus flabellifer* is now grown all over India. It is a national tree of Cambodia and is found in Southeast Asia, where it is extremely populated. It is also regarded as a permanent gift from nature, able to thrive in semi-arid and dry environments. The plant was resilient to any unfavorable weather conditions. This plant is known by several distinct names in several Indian languages, including Talgachh and Tarkajhar in Bengali and Hindi. It's called Lulu or Tadi in Telugu. In Malayalam, it is also known as "Karimpana." It is also known as the Toddy palm, Tala palm, Brab tree and Fan palm in English.

India stands first in the world in terms of its wealth of palmyra (*Borassus flabellifer* L). Its population is nearly 122 million palms (Vengaiah *et al.,* 2013). It grows in Tamil Nadu, Bihar, Orissa, and Andhra Pradesh. Southern Indian states are rich in palm resources. The palmyra palm offers enormous economic possibilities. It is a perennial plant with a maximum growth length of 30 meters and a lifespan of 100 years. According to Velimuthu (2020) and Sridevi Krishnaveni *et al.* (2020), it begins to yield after 15 years in areas with abundance of water sources and after 25 years in desert places.

Classification (Veda Priya Gummadi, *et al.,* 2016)

Kingdom: Plantae

Sub-Kingdom: Tracheobionta

Super-division: Spermatophyta

Division: Magnoliophyta

Class: Liliopsida

Subclass: Arecidae

Order: Arecales

Family: Arecaceae

Genus: *Borassus*

Species: *flabellifer*

Every part of the palm is useful for the welfare of the people; more than 88% of the Palmyra is used. It serves as food (fruit, sap, young shoots) and as a building material (the stem, the leaves). Fruits mature during august and the ripe fruits fall from the palm during September and October. Each female palm bears 10-20 bunches of about 200-300 fruits per year. When the fruit is very young, top of the fruit is cut off. We would find usually three sockets inside and these contain a kernel which is soft as jelly, and translucent like ice, and it is accompanied by a watery sweetish liquid. The mature fruit is usually tossed over low burning fire and the skin is peeled off to expose the juicy fruit. The fruit is squeezed and the pulp is removed. The pulp in itself is sweet and creamy and delicious to eat. The fresh pulp is rich in vitamin A and vitamin C. The entire fruit contains about 40% of undiluted pulp which is dark yellow in color which has its characteristic flavor and bitterness.

Figure 1: The structural component of *Borassus flabellifer* plant with stick and leaves

Historical significance of palmyra

Since palmyra is the state tree of Tamil Nadu, it was chosen in 1978 due to its widespread distribution and significant impact on cottage and rural industries (Kanthimathi, 2015; Sridevi Krishnaveni *et al.*, 2020). Up to 762 meters above sea level, this plant may thrive in a variety of unfavorable agroclimatic situations, including plains, hills, valleys, and seashores.

During ancient times, Palmyra has been exposed to Tamil culture. Throughout a period spanning over 2500 years, the ancient sages, rishis, and scholars engraved ancient scriptures into mature palmyra leaves, or olai chuvadi, as a means of transmitting their accumulated knowledge and wisdom. These remarkable benefits are a gift from nature. Thiru Arunachalam's book 'Thalavilasam' in Tamil documents the evidence of bondage between Palmyra and ancient India, a study that looked at the tree's more than 801 applications. This tree is known by Mahatma Gandhi as the cure for poverty. In Tamil, it's also known as "Karpakatharu," which translates to "wish tree" in English. This tree's notoriety stems from its ability to endure severe drought and other unfavorable weather conditions, as well as its economical use of all plant components.

Palmyra's geographical distribution

A variety called *B. flabellifer* was chosen from the native Arica plant *B. aethiopum.* There aren't many writers who claim that *Borassus* is indigenous to Africa. It can be found mostly in India, Burma (Myanmar), and Cambodia, and spread from there to South-East Asia to New Guinea. Despite its wide spread, there are currently no trustworthy data on its area and productivity from many of these nations. The palm is primarily used in wild regions. Ten million palm trees cover 25000 acres in Sri Lanka, with two thirds of them in the Jaffna district. 60 million palm trees are found in India, with two thirds of those trees found in Tamil Nadu (Aman *et al.,* 2018 and Sridevi Krishnaveni *et al.,* 2020). 2.5 million palm trees are found on 25 000 hectares in central Burma (Myanmar), and 1.8 million are found in central Cambodia. The toddy palm grows in Central and East Java, Indonesia. The average smallholder in Burma (Myanmar) and Cambodia has 30–40 toddy palm trees (25 male, 15 female). It is widely grown throughout Asia, particularly in Bangladesh, Myanmar, Sri Lanka, and India (Golly *et al.,* 2017 and Sridevi Krishnaveni *et al.,* 2020). The semi-arid regions of Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Bihar, Karnataka, and Maharashtra are adorned by palmyra palms that add beauty to the parched terrain. About 102 million palm trees grow in India, with Tamil Nadu holding half of the total.

India has the greatest number of Palmyra (85.9 million), according to Veilmuthu (2020). Tamil Nadu is home to 51 million, or 60% of this total. With 51.9 million trees, the majority is found in Tamil Nadu, with Thoothukudi district holding the top spot. According to Kanthimathi (2015) and Sridevi Krishnaveni *et al*. (2020), the district of Ramanathapuram is the most productive and largest of all the districts. On 15,000 hectares, Madurai is home to 0.5 million palm trees.

Dietary qualities of palmyra palm

Fruit pulp from palmyra trees could be used commercially to make food products and animal feed. According to Sahni *et al*. (2014), the nutritional analysis of the roots reveals that they include 8.54% protein, 23.53% carbs, 7.29% crude fiber, and insignificant fat content. Additionally, the roots are high in calories. It is abundant in minerals including iron, zinc, potassium, calcium, phosphorus, thiamine, and riboflavin as well as vitamins A, B, C, and their precursors. Palm jaggery, sometimes referred to as Palmyra palm sugar, is a naturally occurring sweetener. In comparison to cane sugar, it has fewer calories.

According to Vivek *et al*. (2011), palm sugar is exceptionally beneficial in preventing and lowering obesity. It also gives the body a consistent and steady amount of energy and is high in several nutrients, including vitamins B1, B2, B3, B6, and C. Vitamin A, calcium, iron, zinc, and copper are among the nutrients found in toddies. Additionally, the fermented sap raises thiamine, riboflavin, and niacin levels. The sprout's stem is incredibly nutrient-dense and fibrous (Shirisha *et al.,* 2018).

Table 1: Nutritional components of neera or jiggery of fruit pulp or tuber in 100cc

Moisture	86.6g	**Protein**	350g
Reducing sugar	998mg	**Ash**	0.53g
Calcium	143mg	**Phosphorus**	10mg
Tron	0.30mg	**Ascorbic acid**	15.74mg
Thiamine	82.3mg	**Riboflavin**	44.4mg
Niacin	674.4mg	**TSS**	12.5 %

Table 2: Nutrient composition of palmyra fruit pulp

Consituents	**Quantity**
Moisture (g)	79.1
Energy (k cals)	87
Protein (g)	2.8
Fat (g)	1.0
Total carbohydrates (g)	18.5
Sugars	14 16
Crude fibre	15
Ash	4.3

Phytochemical characteristics of palmyra palm

Products made from palmyra have significant pharmacological qualities, including those that are anti-inflammatory, anti-arthritic, cytotoxic, antioxidant, antibacterial, analgesic, antipyretic, hypoglycemic, and antioxidant (Veda Priya Gummadi *et al.*, 2016). The many components that make up *Borassus flabellifer* such as Gums, albuminoids, steroidal glycosides, lipids, carbohydrates like sucrose, and spirostane-type steroids like dioscin and borassosides are among them (Jerry, 2018). The *Borassus flabellifer* seed coat extract is mostly antibacterial in nature. The male plant exhibits strong anti-inflammatory properties in its inflorescence. Plant roots have cooling, diuretic, and medicinal properties (Arunachalam *et al.*, 2011; Sridevi Krishnaveni *et al.*, 2020).

Antioxidant action may be related to the high concentration of phenolic chemicals, saponins, and crude flavonoids (Pramod *et al.*, 2013). Worm infestation, nausea, vomiting, and skin inflammations can all be treated with fruit pulp. It serves as a livertonic in addition to an expectorant. A thin layer of palm fruit jelly applied to the affected area has a calming effect and instantly reduces the itching brought on by prickly heat. The body becomes dehydrated in the summer, thus eating palm fruit helps to keep the body hydrated. Treatment for stomach disorders and other digestive issues is successful when using it. It serves as a laxative as well. For those following a diet, palm fruit is a good choice. Both in children and adults, malnutrition can be avoided (Jerry, 2018). Consuming leaves, bark, Neera and roots is beneficial for preventing disease since they include various phytochemicals, such as polyphenols, vitamins, minerals, proteins, and so on (Jamkhande *et al.*, 2016; Sridevi Krishnaveni *et al.*, 2020).

The mature tree stalk's flower sap is highly valued for its exceptional properties as an amebicide, stimulant, laxative, diuretic, tonic, and antiphlegmatic. This sap is recommended to treat liver diseases since it contains sugar that counteracts toxicity (Saranya, 2016). All types of ulcer-related illnesses can be treated with fermented fresh toddy (Jana, 2017).

Economic importance of Palmyra tree and its value added by-products

The leaves of palm tree are used as thatching roofs, fence, mats, baskets, fans, hats, umbrellas, buckets, sandals etc. Senesced leaves are utilized as fuel for cooking and it was also used as an organic fertilizer in agriculture. Mesocarp of the matured fruit will contain small quantity of fibre which is used for making decorative products and toys. Palmyra palm trunks were used in construction of thatch sheds and also as timber in replacement of wooden poles. Tough and long fibre extracted from petiole is used for making ropes.

The stem of the palmyra palm tree is best for making water pipes. The sap extracted from the inflorescence of Palmyra palm is called as “Neera” which is a good source of minerals like calcium, phosphorus and iron and vitamins. Palm fruit is very nutritive and it is a summer refresher. The soft orange-yellow mesocarp pulp of the ripe fruit is edible as it is a rich source of vitamin A and C (Chitra Varadaraju *et al.*, 2020). When the crown of the tree is cut, an edible cake is obtained from which the leaves grew out. This is called "Pananchoru" in Tamil.

Sathya *et al*. (2020) reported that the toddy is one of the by-products of palm tree. It is produced by fermenting the pulpusing yeasts and bacteria. The fermented toddy consists of 4-8% of alcohol content. Toddy palm wine is one of the products which are produced by fermenting the flower saps (Kurian, 2007). It gives sweet wine with strong smell. Palm toddy is a traditional drink and refreshing quality. After fermentation, the collected toddy becomes sour is called *Tadi* in Marathi and *Kallu* in Tamil. It should be consumed within 24 hours. Palm Gur has more amounts of nutritional and medicinal properties. Unfermented tree sap (neera) is processed into palm jaggery.

The quality of Gur can be enhanced by adding lime or any other citrus to neera before heating the juice. Palm sugar is the crystals made by processing of neera at 110 °C with little phosphate. Palm oil is separated by wet processing of palm fruit. Palm toffee is made by mixing and processing of fruit pulp with sugar, skim milk powder, glucose, maida and starch. Processing of vinegar, chilli powder, salt, mustard seeds and boiled oil with chopped palm in air tight container is done to produce palm pickle. The palm honey is obtained by heating the filtered neera in iron pan. The perfect consistency is achieved by continuous stirring while boiling for about 2 to 2.5 hours.

Figure 2: (a) *B. flabellifer* fruit & (b) Seed coat (endocarp) of *B. flabellifer* fruit

Figure 3: Palmyra sprout

Sankaralingam *et al.* (1999) have also reported variety of value-added products like, palmyra tuber flour and rava, palmyra tuber laddu, palmyra tuber-soya laddu, Thavan halva, fruit squash, fruit leather, nungu candy, nungu peda, nungu sharbat, neera khova, neera pongal and neera payasam, palmyra tuber payasam, palmyra tuber idli, palmyra tuber upma, Thavanpeda.

Nanotechnology

Nanotechnology is defined as the study of manipulating matter on an atomic and molecular scale. Professor Norio Taniguchi of Tokyo Science University established the word "nanotechnology" in 1974 as the processing of material separation, consolidation, and deformation by a single atom or molecule (Choi *et al.,* 2008; Chikdu *et al.,* 2015).

Nanotechnology is a fast-growing science that involves the design and synthesis of nanoparticles with sizes ranging from 1 to 100 nm. It is a new field that has applications in a wide range of industries, such as food, medicine, agriculture, optics, cancer theranostics, cosmetics, and catalysis (Abbasi *et al.*, 2020).

Researchers have recently focused a great deal of interest on metal nanoparticles because of their many distinctive properties as compared to bulk, as well as their applications in cancer therapy, antimicrobial agents, diagnostics, cell tagging, and medication (Krishnan *et al.*, 2016). One of the most significant fields of cancer treatment is nanotechnology, which offers alternatives to the creation of controlled release systems for the management of various illnesses and lessens the adverse effects of medications. Based on their composition, a variety of nanosystems can be categorized, such as inorganic, lipid, or polymeric ones that allow for the reformulation and improvement of currently available cancer medications (Thorley and Tetley, 2013). Nanobiotechnology, which focuses on the production and use of nanoparticles, is crucial to the growth of a number of economic sectors, including food, cosmetics, agriculture, pharmaceutical distribution, and carcinogenic theranosis (Iqbal *et al.,* 2018; Iqbal *et al.,* 2019).

Plant extracts are now frequently used in green synthesis because to their rich phytochemical profile, which includes phenolic, flavonoids, and alkaloids. These phytochemicals effectively stabilize and chelate biogenic nanoparticles (Iqbal *et al.*, 2018). In addition to controlling NP size and form, plant extract may be a useful agent for capping and decreasing. Additionally, researchers have focused on the plant mediated production of metallic nanoparticles (Kar and Ray, 2014).

Green synthesis of metal oxide Nanoparticles using palmyra products and its applications

Applications in medicine and pharmacological research for different kinds of nanoparticles made from the fruits, sap, leaves, sprout root, and seed of the palmyra tree.

An earlier investigation revealed that the green synthesis of copper and silver nanomaterials using palmyra fruit pulp was assessed for anti-tumor, antimicrobial, and antioxidant activity (Chitturi *et al.*, 2018) and yielded good results against bacteria like *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, and prostate cancer cell lines. Additionally, extract from the palmyra tree fruit was used to create copper-cobalt bimetallic nanoparticles. According to Shehu *et al*. (2020), this nanomaterial worked incredibly well to repel mosquitoes. Palmyra leaves, which have a high concentration of biogenic chemicals, were used to biogenically produce zinc-oxide nanoparticles.

According to Thirumagal and Jeyakumari (2020), palm water has the potential to enhance the antibacterial activity of both gram-positive and gram-negative bacteria. It can also be utilized to biologically generate AgNPs without the need for harsh chemicals. By utilizing an environmentally friendly method, jaggery can be used to create silver nanoparticles that have strong anti-microbial properties against a range of bacterial infections.

Indium tin oxide nanoparticles, with their many uses in the optical, structural, electrical, and medicinal domains, can be biosynthesized using *Borassus* toddy. Merugu *et al.* (2021) reported that palmyra toddy was utilized in the synthesis of bimetallic nanoparticles, specifically Ag/Cu and Cu/Zn, and that these nanoparticles had remarkable anti-tumor and anti-bacterial properties.

According to recent studies, activated charcoal-loaded TiO2 nanotubes made from the waste product of palmyra, tuber peel, have been shown to enhance the photocatalytic degradation of the water pollutant Rhodamine 6G dye (Sivakumar Natarajan *et al.*, 2016). Additionally, extracts from the roots of Borassus are useful in nanotechnology because they can be used to create Ag-Co bimetallic nanoparticles that are highly effective against different populations of Culex quinque fasciatus mosquitoes and can be produced inexpensively and sustainably (Wilson Lamayi, *et al.*, 2020).

Conclusion:

Borassus flabellifer is a medicinal plant with innumerable medicinal qualities for all parts used since ancient times and Tamil Nadu provide a suitable climate for their growth. Besides the plant having unique traditional uses it is also used for people who make their living from this tree using its wood, fruits, sap, stems, petioles and leaves to process a variety of food products, beverages, furniture, building materials, and handicrafts. So it provides an opportunity for the employment and welfare society. In this review, an attempt was made to provide traditional and pharmacological uses of *Borassus flabellifer*. Thus, the phytochemical components of palmyra palm fruit can be exploided for the medicinal applications.

Furthermore, by creating nanoparticles like gold, silver, bimetallic NPs, and zinc oxide, the field of green nanotechnology has advanced the palmyra palm to unprecedented heights and demonstrated good biological applications. Without a doubt, nanotechnology will benefit people and the economy in the coming generations.

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REGENERATIVE MEDICINE: AN OVERVIEW

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Abstract:

Regenerative medicine stands at the forefront of groundbreaking medical paradigms, offering a transformative approach to healing and restoring damaged tissues and organs. This abstract provides a comprehensive overview of regenerative medicine, exploring its fundamental principles, methodologies, and far-reaching implications. Rooted in the harnessing of the body's innate healing mechanisms, regenerative medicine leverages cutting-edge technologies, including stem cell therapy, tissue engineering, and gene editing, to facilitate tissue repair and regeneration. The abstract navigates through the key components of regenerative medicine, emphasizing its potential in treating chronic diseases, injuries, and congenital disorders. Furthermore, the ethical considerations and challenges associated with regenerative medicine are examined, underscoring the need for a balanced approach to its implementation. As a beacon of hope for personalized and regenerative healthcare, this overview sheds light on the current state of regenerative medicine and its promising trajectory in reshaping the future of medical practices.

Keywords: Tissue engineering, Stem cells, Cell therapy, Biomaterials, Tissue regeneration

Introduction:

Regenerative medicine presents a promising avenue for repairing or replacing damaged tissues and organs caused by various factors such as age, diseases, or injuries. It offers potential solutions for chronic ailments, acute injuries, congenital defects, and a broad spectrum of organ-related conditions including dermal wounds, cardiovascular diseases, cancer treatments, and more. In the evolving landscape of medical science, regenerative medicine stands as a revolutionary discipline that holds the promise of transforming the traditional approach to treating diseases and injuries. Rooted in the fundamental principle of harnessing the body's inherent ability to heal, regenerative medicine seeks to repair, replace, or regenerate damaged tissues and organs. This field represents a paradigm shift from merely managing symptoms to addressing the underlying causes of various medical conditions. At its core, regenerative medicine encompasses a diverse set of interdisciplinary approaches, integrating principles from biology, genetics, materials science, and engineering. One of the central pillars of regenerative medicine is stem cell therapy, where the remarkable potential of stem cells to differentiate into various cell types is harnessed for tissue repair. Stem cells can be derived from various sources, including embryonic tissue, adult tissues, and induced pluripotent stem cells (iPSCs), offering versatility and ethical considerations in their application. Tissue engineering is another pivotal aspect, involving the creation of functional tissues or organs in the laboratory for transplantation or repair. This approach utilizes a combination of cells, biomaterials, and biochemical factors to construct structures that mimic the native tissue architecture. Gene editing technologies, such as CRISPR-Cas9, further contribute to regenerative medicine by allowing precise modification of genetic material to correct abnormalities or enhance therapeutic outcomes.

The potential applications of regenerative medicine are vast and encompass a spectrum of medical conditions, including but not limited to cardiovascular diseases, neurodegenerative disorders, musculoskeletal injuries, and congenital anomalies. By addressing the root causes of diseases and promoting tissue regeneration, regenerative medicine offers the prospect of not only alleviating symptoms but potentially curing previously incurable conditions. However, the journey of regenerative medicine is not without challenges. Ethical considerations surrounding the use of embryonic stem cells, the complexities of tissue engineering, and the potential for unintended consequences with gene editing technologies necessitate careful navigation and thoughtful regulation. Striking a balance between scientific innovation and ethical responsibility is crucial for the responsible advancement of regenerative medicine. Currently, transplantation remains the conventional method for treating organ or tissue failures but faces challenges like donor scarcity and immune complications. Regenerative medicine emerges as a potential solution to overcome these hurdles. This field incorporates diverse strategies involving materials, cell generation, or a combination of both to substitute missing tissues, effectively restoring them structurally and functionally, or to contribute to the natural healing process. While humans have limited regenerative abilities compared to some lower vertebrates, leveraging the body's healing response is a significant aspect. This chapter aims to explore market-available regenerative medicine therapies. It will delve into altering the body's physiological environment using materials, living cells, or growth factors to either replace lost tissue or bolster the body's natural healing mechanisms. Additionally, it will discuss strategies to enhance the complexity of implanted grafts and optimize recently developed cell sources. Finally, it will explore potential future directions in the field. The term "regenerative medicine" encompasses tissue engineering activities. Several therapies have received FDA approval and are currently available commercially, emphasizing cell-based therapeutic paradigms. These therapies utilize either a patient's own cells or donor cells to contribute to tissue structure and function. Autologous cells, extracted from the patient's tissue and expanded in culture, are used in treatments like Carticel, targeting focal articular cartilage defects. Alternatively, allogeneic cells with low antigenicity, like human foreskin fibroblasts, are employed in products such as GINTUIT for wound healing, allowing for off-the-shelf tissues. Materials are crucial components in regenerative medicine strategies as they can mimic native tissue's extracellular matrix, guide cell behavior, and locally deliver growth factors. Various materials like 3D polymer scaffolds, decellularized donor tissues, and bioactive glass-based grafts play roles in different therapeutic approaches. They provide structural support and cues for regeneration or graft integration. Incorporating growth factors into biomaterials can promote healing and regeneration but may lead to complications due to the challenge of controlling factor release kinetics. Although FDA-approved regenerative medicine products demonstrate varying degrees of efficacy, they generally offer better or comparable healing outcomes to preexisting treatments. However, these therapies may not completely resolve injuries or diseases. Bringing new products to market in this field demands substantial investments of time and money, with cell-based products facing a more rigorous approval process than acellular ones. Despite these challenges, regenerative medicine continues to hold promise for transforming healthcare.

Therapies at the preclinical stage and clinical testing

A comprehensive exploration into regenerative medicine unfolds with various strategies at different stages of development—spanning preclinical to clinical investigation. These strategies are broadly categorized into three segments: (i) reproducing tissue and organ structure using scaffold construction, 3D bio-printing, and self-assembly; (ii) integrating grafts within the host by fostering vascularization and nerve connections; and (iii) modifying the host environment to stimulate therapeutic responses, particularly through cell infusion and immune system modulation. Additionally, novel cell sources for regenerative medicine purposes will be touched upon. Efforts to recreate healthy tissue structure often prove crucial for successful tissue engineering. One such strategy involves decellularizing organs—removing immunogenic components while preserving structure, mechanical properties, and material composition. This approach has been used alongside bioreactors and in animal models for various organ systems like lungs, kidneys, liver, pancreas, and heart. Decellularized tissues without recellularization have even been deployed as medical devices and used to mend significant muscle defects in a human patient. Challenges, however, persist such as alterations in mechanical properties and the potential degradation of processed tissues post-transplantation.

Synthetic scaffolds represent another avenue to mimic tissue properties. These scaffolds, fabricated from natural or synthetic materials like hydrogels or polymers, are engineered to be biodegradable, allowing gradual replacement by seeded cells and host cells. Examples include tissue-engineered vascular grafts (TEVGs) utilized in treating congenital heart defects in patients. Composite scaffolds combining different materials can improve performance, as seen in bladder replacements for human patients and bone regeneration in critical defects. Medical imaging aids in creating patient-specific scaffolds, leveraging CT or MRI scans to customize scaffolds. Innovative techniques, like 3D bioprinting, offer high-resolution control over material and cell placement within constructs. Inkjet and microextrusion bioprinting strategies have been instrumental in engineering cartilage and fabricating aortic valve replacements, respectively. Although promising, bioprinting technologies face challenges in feature resolution, cell viability, and printing resolution. Scaffold-free approaches, like cell sheet technology, rely on temperature-responsive substrates to retrieve sheets of cells while preserving cell-cell adhesion and deposited extracellular matrix (ECM) molecules. Autonomous cellular self-assembly also proves effective in creating tissues without scaffolds. For instance, vascular cells aggregated into multicellular spheroids generated hollow, branching structures resembling a vascular network once the cells formed a continuous structure. Understanding the biological mechanisms driving self-assembly will be crucial for harnessing its full potential.

Therapies at the preclinical stage and those advancing to clinical testing represent critical junctures in the drug development pipeline, each marked by distinct processes and considerations. The preclinical stage is characterized by rigorous laboratory and animal testing to evaluate the safety, efficacy, and pharmacokinetics of a potential therapeutic intervention. Researchers conduct in vitro experiments, employing cell cultures to understand the basic mechanisms and biological effects of the treatment. Animal models are then employed to assess the therapeutic candidate's performance in a living system, providing valuable insights into its potential toxicity, optimal dosage, and overall safety profile. Data generated during the preclinical phase guide decisions on whether to advance the therapy to human clinical trials. Clinical testing, encompassing Phase I to Phase III trials, involves evaluating the therapeutic's safety and efficacy in human subjects. Phase I trials focus on safety, determining the maximum tolerated dose and potential side effects in a small group of healthy volunteers. Successful completion leads to Phase II trials, where the therapy is administered to a larger group of individuals with the targeted condition. This phase assesses the treatment's efficacy, optimal dosage, and potential adverse effects. If promising results are obtained, the therapy progresses to Phase III trials, involving an even larger and more diverse patient population. These trials aim to confirm the therapeutic's effectiveness, monitor side effects, and gather additional information on its overall benefits and risks. Throughout these stages, regulatory agencies closely oversee the development process to ensure patient safety and data integrity. If the therapy successfully navigates these phases and demonstrates significant benefits, regulatory approval may be sought, allowing the therapy to reach the broader patient population. The transition from preclinical research to clinical testing is a pivotal and resource-intensive phase, marking the translation of scientific discoveries into tangible advancements in healthcare. The careful and systematic progression through these stages is essential for identifying promising therapies, mitigating risks, and ultimately delivering safe and effective treatments to those in need.

Integrating graft tissue by inducing vascularization and innervation

Integrating graft tissue successfully into a host environment is a crucial aspect of various medical procedures, including tissue transplantation and regenerative medicine. A key challenge in this process is ensuring proper vascularization and innervation, which are essential for the graft's survival and integration with the surrounding tissues. Vascularization is the process of establishing blood vessel networks within the graft to facilitate nutrient and oxygen exchange. Adequate blood supply is vital for the graft's metabolic needs, ensuring its viability and functionality. Researchers and clinicians employ various strategies to induce vascularization, ranging from the use of angiogenic growth factors to the incorporation of biomaterials that support blood vessel formation. Additionally, advancements in tissue engineering techniques, such as the creation of pre-vascularized constructs, aim to enhance the integration of grafts by providing a vascular framework for rapid connection with the host circulatory system. Innervation, or the establishment of nerve connections, is another critical aspect of graft integration, particularly in tissues with a high degree of sensitivity or function. Nerve growth and guidance cues are essential to attract and direct nerve fibers into the graft. Incorporating nerve-promoting factors or employing bioactive scaffolds that support nerve regeneration are strategies employed to encourage innervation. The goal is to establish functional connections between the graft and the host's nervous system, enabling proper communication and responsiveness. The simultaneous promotion of vascularization and innervation is often pursued to enhance the overall success of graft integration. Coordinated efforts in tissue engineering focus on developing constructs that not only mimic the structural and functional properties of the native tissue but also actively promote the establishment of blood vessels and nerve connections. This multidimensional approach aims to create grafts that seamlessly integrate into the host environment, restoring both form and function. Integrating graft tissue by inducing vascularization and innervation is a complex yet essential aspect of regenerative medicine and transplantation. By addressing the challenges associated with blood supply and nerve connectivity, researchers and clinicians strive to enhance the success and long-term viability of grafts. Advancements in biomaterials, tissue engineering, and growth factor therapies continue to contribute to the development of strategies that facilitate the seamless integration of grafts, offering new possibilities for regenerating damaged or lost tissues. For implanted grafts to effectively integrate with the body both functionally and structurally, particularly for cell-based implants, establishing a connection with the host vasculature is crucial. Cells within the body are generally situated close to capillaries, ensuring efficient nutrient exchange and oxygen diffusion within a 100μm proximity from the nearest capillary. To vascularize engineered tissues, leveraging the body's natural angiogenic response via angiogenic growth factors like VEGF, Ang, PDGF, and bFGF proves essential. However, effective application of these growth factors necessitates sustained release to stimulate robust angiogenic responses without potential toxicity or systemic effects. Creating functional vascular networks involves initiating and maturing newly formed vessels through sequential delivery of angiogenic factors. Additionally, mimicking developmental processes using promoters and inhibitors of angiogenesis from distinct spatial locations can create precisely defined angiogenic zones. Another approach involves prevascularizing the graft or target site before implantation, allowing endothelial cells to self-organize into vascular networks on an appropriate scaffold. This method results in better vascularization and tissue-specific functionality.

Prevascularization of the graft at the target site or creating a vascular pedicle for the engineered tissue facilitates successful transplantation. This has been demonstrated in cases of bone and cardiac patches, where placing a scaffold around a large host vessel or richly vascularized tissue before moving the engineered tissue to its final anatomic location has proven successful. Engineered vascular networks through microfluidic and micropatterning techniques are being explored to connect to major arteries. Site prevascularization enhances cell survival and function. For instance, a recent study showcased improved pancreatic cell efficacy after catheter device placement that allowed the site to become vascularized due to the host foreign body response to the material. Additionally, proper innervation by the host is crucial for tissue integration, especially in tissues requiring motor control or sensation. Strategies inducing nerve growth via growth factors or patterning hydrogels with channels loaded with suitable extracellular matrices and growth factors have shown promise in guiding nerve growth and supporting nerve regeneration after injury. The connection between angiogenesis and nerve growth is being explored to promote axon regrowth in regenerating skeletal muscle through controlled VEGF delivery using biomaterials.

Altering the host environment: Cell infusions and modulating the immune system

Altering the host environment is a crucial strategy in various medical interventions, particularly in the fields of cell therapy and immunomodulation. Cell infusions, a prominent approach in regenerative medicine, involve the introduction of exogenous cells into the host to restore, replace, or enhance cellular functions. This process necessitates careful consideration of the host microenvironment to optimize the survival, integration, and functionality of the infused cells. Researchers explore various methods to alter the host environment favorably, including the use of supportive biomaterials, engineered scaffolds, and the incorporation of signaling molecules that promote cell adhesion, migration, and differentiation. These efforts aim to create an environment conducive to the effective incorporation of infused cells into the host tissue. Modulating the immune system is another key aspect of altering the host environment, particularly in the context of transplantation, autoimmune diseases, and immunotherapies. The immune system plays a pivotal role in determining the fate of introduced cells or therapeutic agents, and controlling immune responses is crucial for achieving successful outcomes. Immunomodulation strategies involve the use of immunosuppressive drugs, regulatory T cells, or engineered cells with modified immune-modulating properties. The goal is to create an environment that minimizes host immune responses against transplanted tissues or therapeutic cells while maintaining overall immune function. Cell therapies often require careful consideration of immune compatibility to prevent rejection of transplanted cells. Strategies such as HLA matching or the use of induced pluripotent stem cells (iPSCs) with reduced immunogenicity are explored to improve the compatibility between donor and host cells. Additionally, advancements in gene editing technologies, such as CRISPR-Cas9, enable the modification of cells to evade immune detection or enhance their resistance to immune-mediated destruction. In immunotherapy, the modulation of the host immune system is leveraged to target and eliminate cancer cells or combat autoimmune diseases. Immune checkpoint inhibitors, chimeric antigen receptor (CAR) T-cell therapies, and other immunomodulatory approaches aim to enhance the host's immune response against specific targets while minimizing collateral damage to healthy tissues. Altering the host environment through cell infusions and modulating the immune system represents sophisticated strategies with broad applications in regenerative medicine and immunotherapy. The success of these interventions relies on a deep understanding of the host microenvironment, immune responses, and the development of precise techniques to optimize the therapeutic effects while mitigating potential risks. As these fields continue to advance, the ability to strategically alter the host environment holds great promise for improving patient outcomes and expanding the scope of therapeutic interventions. Administration of cells can trigger therapeutic responses through indirect mechanisms, such as releasing growth factors and interacting with host cells, without substantial incorporation into the host or forming bulk tissue. For instance, human umbilical cord blood cells infusion facilitates stroke recovery by enhancing angiogenesis, which may have induced neuroblast migration to the injury site. Similarly, transplanted macrophages can support liver repair by activating hepatic progenitor cells. Some cell therapies correct the injured or diseased environment by altering the extracellular matrix (ECM), temporarily rectifying conditions like epidermolysis bullosa, a rare genetic skin blistering disorder, by introducing allogeneic fibroblasts that deposit missing collagen. Mesenchymal stem cells (MSCs) represent a prime example; they're extensively researched for cardiac regeneration post-infarction and treating various conditions like graft-versus-host disease, multiple sclerosis, and brain trauma. Despite concentrating in the lungs and poor engraftment in diseased tissues, MSCs demonstrate positive effects, suggesting systemic paracrine action is sometimes adequate for therapeutic response. In certain scenarios, cell-to-cell contact may be necessary. MSCs, for instance, inhibit T-cell proliferation and dampen inflammation, believed to rely partly on direct contact with host immune cells. However, intravenously administered cells often face rapid clearance, limiting their efficacy. Strategies like hydrogel encapsulation, immune cloaking, and genetic modifications aim to improve cell residency and targeting to specific tissues.

The immune system, known to modulate regeneration, presents challenges and opportunities in tissue integration. Immune reactions, particularly immune rejection, hinder graft integration with allogeneic cells. Immune engineering shows promise in inducing allograft tolerance by manipulating immune cell responses, potentially reducing inflammation accompanying foreign object implantation. Harnessing immune responses to actively promote regeneration through controlled release of cytokines or altering local immune reactions could pave the way for effective regeneration. Regarding cell sources, while stem, progenitor, and differentiated cells from adult and embryonic tissues are explored in regenerative medicine, adult tissue-derived cells dominate clinical usage due to availability and perceived safety. Hematopoietic stem cells (HSCs), for instance, can expand significantly in vitro, albeit with potential loss of repopulation potential; coculture with cells from the HSC niche or on bone marrow-mimicking environments may enhance maintenance of stemness during expansion. Embryonic stem (ES) cells and induced pluripotent stem (iPS) cells offer potential infinite cell sources for regeneration and are advancing towards clinical use, showing promise in several clinical trials. iPS cells, especially those generated from the patient's own cells, offer a way to circumvent ethical issues and potential rejection. However, the safety concerns related to tumor formation and ensuring cell fate control remain pivotal in their application. High-throughput screens, controlled reprogramming strategies, and optimized culture conditions aim to address safety and fate control concerns, ensuring safe application in regenerative medicine. The development of synthetic materials for cell culture in defined conditions and strategies to direct lineage specification while minimizing pluripotent cell persistence further bolster safe application in therapeutic settings.

Conclusion:

Regenerative medicine has made significant strides, leading to FDA-approved therapies for various pathologies. Through extensive research, advanced grafts utilizing scaffold materials and cell manipulation technologies have been developed, allowing precise control over cell behavior and tissue repair. These scaffolds can be customized to fit a patient's anatomy, enabling meticulous positioning of cells. Strategies are evolving to enhance graft integration with the host's vasculature and nervous system, primarily via controlled release of growth factors, seeding vascular cells, and leveraging the body's healing response, including immune system modulation. The pursuit of new cell sources aims to address past limitations stemming from limited cell supply. However, several critical aspects are pivotal for the field's progression. Firstly, controlling stem cell behavior, whether derived from adult tissues or induced, is crucial for enhancing safety and efficacy post-transplantation. Mimicking specific stem cell niches and microenvironments that offer cues like morphogens and physical properties may optimize therapeutic cell responses. Secondly, developing technologies for creating fully vascularized grafts that can be connected to host vessels during transplantation is crucial for graft survival. Thirdly, fostering a pro-regeneration environment within patients could significantly enhance regenerative medicine outcomes. Understanding the immune system's role in regeneration and devising technologies that promote desirable immune responses will be key. Factors like patient age, disease state, and the microbiome's influence on regeneration also warrant deeper exploration for advancements in the field. Lastly, creating 3D human tissue culture models of diseases could revolutionize testing regenerative medicine approaches in human biology, diverging from current animal models used in preclinical studies. More accurate disease models could elevate the efficacy of regenerative medicine strategies and streamline the translation of promising approaches into clinical applications.

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THE ADVANCEMENT OF 3D FOOD PRINTING TECHNOLOGY: A REVIEW

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Abstract:

The additive manufacturing technology has been created to directly construct physical model from 3D model without Mold and die. Three-dimensional food printing (3DFP) leads to advances in digital gastronomy by targeting consumers' specific requirements for nutrition customization and visual appeal. To help dysphagia increases their food intake. Dysphagia, or difficulty swallowing, is prevalent in elderly people and patients suffering from debilitating illenesses.3DFP is a potential solution to overcome drawbacks of current food customisation techniques, such as lower production efficiency and high manufacturing cost. We discuss several machines for food priniting.3DFP with an emphasis on the plant-based food (edible material) to treat major diseases. We also research about textural and structural properties, binding and colouring agent of 3DFP. Moving forward, future research into food printer development should aim to improve on these strengths, eliminate these limitations and incorporate new capabilities.

Introduction:

Cost, taste, experience, nutrition and convenience are the main factors to attract the consumer towards any food product. As the lifestyle of people is changing day by day, thus, convenient food plays an important role as it is attractive and have health benefits. Due to the low price and high glycemic index, convenient foods are highly consumed by the people all around the world. An incremental awareness about health concepts and functional value of the foods among people also flavours the consumption of nutritional rich foods (Somya Singhal *et al*.,2020). Dysphagia is a debilitating condition whereby a patient is unable to swallow food in a safe manner. This condition is usually the result of weakening or loss of muscle function responsible for the reflex actions that take place during deglutition. Dysphagia typically follows neurological disorders such as stroke, Parkinson disease and progressive dementia, all which scale in occurrence with age. Across a sample size of 3,174 elderly hospital patients 65 years or older, dysphagia was found to affect 7.6% of the patients. However, in the case of a nursing home, prevalence of dysphagia peaks up to 60%. It is also observed that 45-62% of stroke patients experience some form of dysphagia. The advent of 3D printing technology will allow us to transform these shapeless purees into 3D structures that patients recognize as conventional food then, hopefully, increase the food intake of patients with dysphagia, other advantages that 3D printing can confer to healthcare provides is the customization of specific nutritional content by carefully tailoring the food ink formulations (Cavin *et al.*, 2018). There are many potential advantages of 3D printing technology applied to food sector, such as customized food designs, personalized and digitalized nutrition, simplifying supply chain, and broadening the source of available food material. Using this technology, some complex and fantastic food design which cannot be achieved by manual labour or conventional Mold can be produced by ordinary people based on predetermined data files that comprise culinary knowledge and artistic skills from chefs, nutrition experts, and food designers. It also can be used to customized confectionary shapes and colourful images onto surface of solid edible substrates (Zhenmin *et al.*, 2017). There are many different approaches to make food purees printable. However, the underlying mechanism to obtain a successful 3D printout are very similar, regardless of the additive used. Overall 3DFP has several potential advantages for some applications, including customizable food production, reduced manufacturing costs, reduced food transport requirement, reduced packaging needs, and a lower environmental impact.

Additive manufacturing technology

The 3D food printing has been classified into three categories namely extrusion based printing, binder jetting and inkjet printing.

Extrusion based printing

The printing constructs food model by extruding food through a nozzle with constant pressure. It is based on the principle of extrusion and deposition. The starting material of extrusion-based food printing can be both solid and paste (soft) with low viscosity. The process done by extruded through nozzle by ram pressure to create food shape layer- by- layer. The result shown that the nozzle diameter, the nozzle movement speed and the extrusion rate affect the quality of 3D food printing excluding the nozzle height.

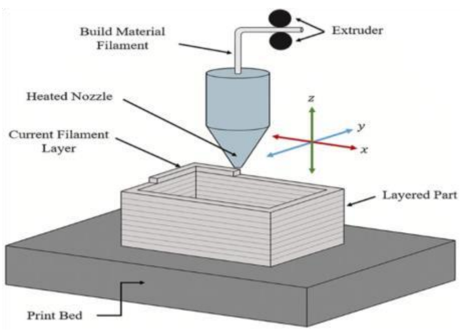

Figure 1: Extrusion Based Printing

Binder jetting

This constructs model by using a binder selectively bond layer of powder. In this process small droplets of binder with diameter loss than 100µm are successively deposited on to the powder bed surface, which those are a drop-on droplet print head surface on rater scanning pattern. The binder has to be suitable low viscosity liquid based in which surface tension and ink density- are suitable property to prevent spreading from nozzle.

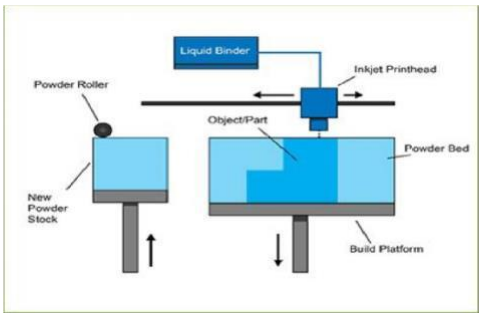

Figure 2: Binder jetting

Inkjet printing

This process generally operates by using thermal or piezoelectric heads. The inkjet printing dispenses a material steam of droplets from a thermal head to certain regions for creating the surface filling or decorating on food surface such as cookie, cake and pizza. There are two types of inkjet printing method; A continuous jet printing and a drop-on-demand printing. The inkjet printer normally handles low viscosity, liquid- based, powder-based materials. Therefore, it does not find application on construction of complex food structure (Papakura *et al.*,2018)

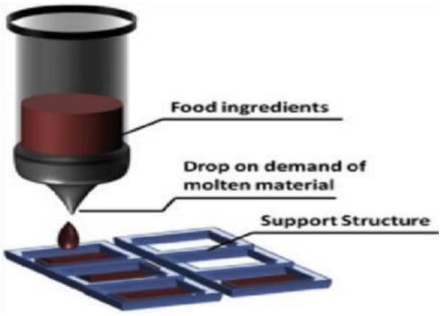

Figure 3: Inkjet Printing

Dysphagic patients

It refers to the difficulty in swallowing food; which manifests as an abnormal delay in moving food in the form of alimentary bolus during swallowing Oropharyngeal dysphagia (OD) causes coughing, choking and difficulty in initiation of swallow because of residue being left in oral cavity. All these condition led to poor nutrition, dehydration and weight loss due to less food intake by patients. So, food must be made soft enough to chew and safe to swallow. This is done by changing the textural properties of the food. Texture modification can be accomplished through the addition of food additives, stabilizer, thickness, viscos elasticity modifier like agar, gellant gum, locust bean gum, kappa carrageenan, and xanthan gum among others. Most of the 3DFP studies so far only used dehydrated and freeze-dried food powders for extrusionbased printing. The issue of food powder has been addressed in the study of 3D unprocessed vegetables. food inks are prepared from freeze or frozen vegetables are used to print diets that are visually stimulated and texturally safe for consumption by dysphagia patients, vegetables are important source of vitamin, mineral, water and antioxidant in our food, making them are relatively difficult to print due to the highwater content with very low carbohydrate and fat percentage. Rheological properties and textural are modified with hydrocolloids including Xanthan Gum (XG), Kappa Carrageenan (KC) and Locust Bean Gum (LBG). The printability, rheological, textural, and microstructural properties of these inks are characterized extensively. International Dysphagia Diet Standardisation Initiative (IDDSI) test is performed to evaluate the sub stability of the ink formulation for dysphagia patients (Aakanksha *et al.*, 2021). The food material can also be prepared by plant-based material.

Plant based material

In general, the food material is can be divided into two categories. There is the native printable material, non-printable material. The regular composition of a plant-based food help major disease. There are consists of a three material (Ming Shuang *et al*.,2021).

- Hot melt material
- Hydro gel forming extrusion.
- Soft material extrusion.

Charcterization of 3D FPT

Customization of food

The target of food is build-to-order strategy with high production efficiency and lower overriding cost. Consumer may configure or transact food design and fabricate physical product using a nearby of production facility. To archive zero lead time from design to market, plenty of innovation food design websites and mobile apps can assist users on design and order customized food products. All of them will result in big change in customized food supply chains, reduce the distribution cost, simply customized food service, and bring products to customer in a shorter time. A description of this new customized food supply is shown in figure 4. It starts with consumer searching for an online food design platform based on their needs and selecting a food design. The selected food design are fabricated at this Bureau and are eventually delivered to the customers (Jie sun *et al.*,2015).

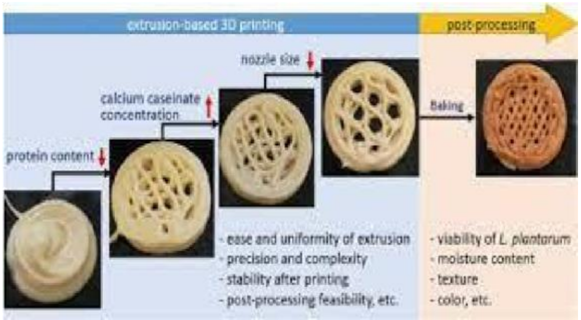

Figure 4: customisation of food

3D printed structure

The printability of food formulation was evaluated based on syneresis, shape, fidelity and structural integrity food Hydrocarbon ate (Hy's) are deemed safe 'a general perception among elderly patients in that Hy's introduce a non-natural taste which may hinder the consumption and acceptance of 3D food. Even when the consumer was given the complete information more than the positive one. consumer survey from the far eastern countries. Pointed towards their performance of food without additives because of additives perceived potential hazards. Hence, the inks with the least amount of Hy's were chosen as the optimized formulation of food type amongst the one with the same point scores. Pea ink was able to form stable self-supporting structure without requiring any additives. Thus, the best garden pea ink was ink formulation 1with no Hy's pea represents the starchiest vegetable in the three defined categories. Starch by itself is used as thickener hence the good printing outcome in pea ink 1 without any Hc addition. Carrot has relatively high-Water Content (WC)% and a median starch content as compared to garden peas. Carrot ink 1 extruded but there were severe syneresis. Also, the shape fidelity and surface quality were poorer the expected. Boy choy represent green leafy vegetable with highest amount of water percentage and lowest starch content among the vegetables chosen for the study. To improve the quality of living for dysphagic patients, an enjoyable, nutritious and safe meal is of the utmost importance. In this regard 3D printing can provide much superior presentation compared to the widely used silicon mould. The 3D printing was assembled together by 3D printed shapes of food inks, showing that more creative, complex and aesthetically pleasing design could be printed using the food inks (Aakanksha *et al.*, 2021).

Favorable material properties

There are many different approaches to make food purees printable. However, the underlying mechanism to obtain a successful 3D printout. They are very similar, regardless of additive used. In pre-extrusion phase, the food formulation must remain fluid. This is commonly enduring that the food material used has a small particle size. In the post-extrusion phase, the printed food has to be able to resist structural deformation after deposition. This can be done by "curing" the printed the food. The non-food application such as bio printing. In these two requirements of printable food formulation, that is alginate and carrageenan. It is therefore beneficial to investigate and if possible, create shear-thinning food inks. The advantage of high shear experienced at the printing nozzle to allow smooth flow through the nozzle and onto the print bed. Once printed, no more shear is experienced and the food's 3D shape may be retained. The hydrocolloids chosen will form a macromolecular gel network that dissenting gels under shear and reforms when at rest. Also, by strictly controlling food particle size and concentration, it is possible to achieve the loose particle cluster arrangement that also imparts shear thinning properties. Some examples of printability –enhancing additives (Cavin *et al.,* 2018).

Potato starch in lemon

Potato starch proved to be good candidate in this case as it undergoes a well-known process called gelatinization. When the starch and lemon juice mixture was cooked in steam 20mins at about 86ºc, the starch granules 1^{st} become swollen due to uptake of water up to the point of rupturing. Once ruptured the amylase and amylopectin were released into the mixture which caused significant increase in viscosity. When it was subsequently cooled at room temperature, a stable gel network gel was formed. One problem with using starch as gelling agent, that it requires a relatively high concentration in order to achieve similar effectiveness as the other hydrocolloids.

Pectin in mixed food puree

Pectin as used as a printability modifier in this case as it is common gelling agent used in the food industry. Depending on the type of pectin used, it can be used in different food system Dimethoxy (HM) form strong gel network when heated the presence of sugar and acids. The sugar being hydroscopic, promotes this network formation as it is able to trap free water molecules in food system. Thus, HM pectin is widely used in preparation of jam or jellies. Low-Methoxy (LM) form gel network in the presence of calcium ions (Ca2+) in adherence to the egg box model. In this study, the type of pectin is not mentioned and was probably procured as mixture of HM and LM pectin. So, addition of pectin contributed to the overall printability.

Gelatin in ground meat

Gelatine is a proteinaceous hydrocolloid which proved useful in this case, where high protein meat is used as the food base. Upon hydration and heating up to 40ºc the gelatine amino acid chains denature and unavelavailing their hydrophilic regroups to bind water. More importantly when cooled down to room temperature, the gelatine chains denature to form random fibrillar collagen like helix structure which cross link to form a thermos reversible gel Network throughout the meaty food matrix.

Cellulose Nanofiber (CNF) on milk powder and starch powder

The CNF are self-prepared from dried and bleached birch craft pulp. The edible hydrogel cannot be classified as a food as it has no nutritional value. Cellulose, semi cellulose, lignin are all non-digestive by human digestive system. Thus, milk powder and starch were added to this gel to form food inks with digestible proteins (from milk) and carbohydrates (starch).

Crystalline Nanocellulose (CNC) and Nano Fibrillated Cellulose (NFC)

Nanocellulose as used as they exhibit good shear thinning properties even ay low concentration. More interestingly, nanocellulose gel network are capable of selfassembly in an aqueous medium. Thus, they are fit based on the guidelines proposed. Also, unlike gelatine or starch, heating and cooling cycles are not required for the formation of nanocellulose gel network (Cavin *et al.*,2018).

Textural and structural properties

Texture

The texture and structure is a sensory properties there are food texture is the most critical factor determined the quality that influence of a bioavailability of a nutritional and a function component. Bioavailability can be derived fraction of nutrient available of utilization. The current literature of a texture perception of food depends on a 3D Food Printing for a textural structure by a information micro and macro scale. The 3DFP customized by the controlling internal structure of a design (Gayler *et al., 2 018).*

Structure

The current literature of the 3D texture depends on a 3D structure which may be described. In 3DFP is customized by an internal of a food structure. This supports the product. The infill by a stronger structure. (e.g.; Star, Line, Square) The infill percentage is consisting of a (1% to 100%) level of infilling. The overall texture and structural properties of 3D printing is based on modified infill pattern and infill level. The material of a dark chocolate raw material has the three hexogen shapes. (cross level- parallel support, no support) (Gayler *et al*.,2018).

Binding agent and colour agent

Binding agent

A substance that makes a loose mixture while stick together. The binding provides linkage. The binding agent are formed by the agents. They are

- Xanthan Gum

- Pectin
- Chitosan

Xanthan gum

The xanthan gum (C35 H49 O29) is an extracellular polysaccharide which is produced through fermentation by a various stain. They are approved by an united states Food and Drug Adulteration (FDA). They have not any restriction they distributed in food industry.

Then it was registered as an emulsifier and a stabilizer (The code of Federal Regulation. Xanthan gum is mostly utilized in a food industry as a stabilizer and emulsifier due to their thickness outstanding characteristics. The production of annual rate of xanthan gum is 5%10%.

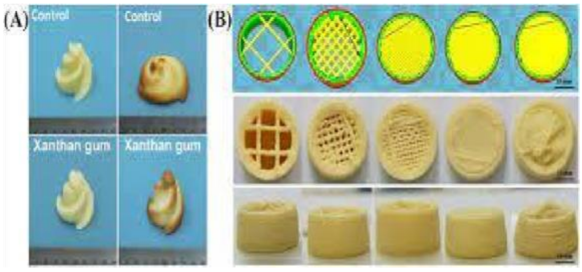

Figure 5: a) Xanthan gum b) Pectin

Pectin

The pectin (C6 H10 O7) is an ionic water-soluble biopolymer one which are main structure acidic hector polysaccharide tertial plant cell. It is the byproduct of the fruit and vegetable pomace. (e.g.; Mango, Apple). It is constituted of a citrus fruit (e.g.; Orange, Lemon). The rich source of pectin is extract from sugar beet pulp. It represented by Fruit and Vegetable, Food And Agricultural Organization Unite Nation and World And Health Organization. The pectin is considered as a natural, safe, non-toxic.

Chitosan

Chitosan (C56 H10 N9 O39) is a biocompatible and biodegradable polymer approved by the European Food Safety Authority (EFSA) generally regarding as safe for consumption. The alkaline structural α-cytosine, the structural component of shrimp cell (Prawn); Crab shell, which contain 70% of chitin. The major bioactive component is present in shell fish (Chua *et al*.,2020).

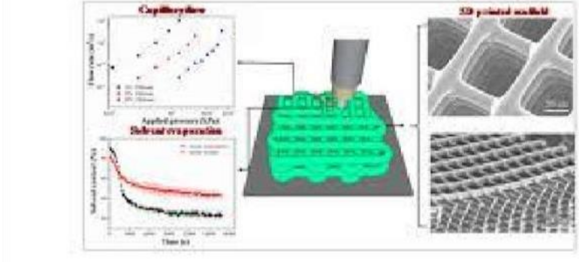

Figure 6: Chitosan

Colouring agent

The colouring agent is a sensory attribute. It is the major sensory of a food product. It is consisting of perception of judge the product for the consumer. The natural food colorant of the addition of functional properties of a food stuff. The synthetic food colorant which is the force of the food industry to replace the natural colorant (Chua *et al.,* 2020).

Application of 3D food printing

Future research for space food

Space food should be compact, lightweight, easy to weight, store and convenient to eat. Early space expeditions including the Mercury and Gemini mission, focused on food research and development to deliver calorie dense, nutritious, and palatable food. Initially, the food was packed in tubes or bite sized cubes, but retort pouches, cans and food bars were developed later. These foods were relatively safe and nutritious but where often unappealing desirable food product should also supply essential nutritious for astronauts to stay healthy during long-term mission. Food is not only essential to the physical health of astronauts also important for the mental health. The mental health of the astronauts is strongly impacted by the quality and diversity of food available. 3DFP can create a wide range of customized food from a small range of food inks. Research have identified the research opportunities to advance 3DFP for in space application and have highlighted the advantage such as nutritional stability, shelf life and acceptability of meals on space mission. Several aspects of food can be improved using 3DFP technology. Currently food developed and packaged for space has limited shelf life, typically only lasting for about three years. The potential to make powdered. Shelf-life ingredients can decrease the risk of spoilage of raw material in space. Alternative protein source could also create meat-like product with good shelf life and quality. These proteins could be stored as powder and then printed into a range of desirable product when needed. Foods can be precise dietary requirement of each astronaut. However, the bioavailability of micronutrient in supplement is often relatively low, which means their health benefits are not being fully synthesized. In corpora ting these nutrients directly into astronaut's meals could significantly improve their bioavailability (Rachael *et al.,* 2022).

Application in millitary

The US Army has shown a great deal of interest in the application of 3DFP in military foods due to the several reasons.1) this technology allows for the production of meals on demand in the battlefield; 2) meals can be customized and personalized depending on individual soldier's nutrition energy requirements; 3) this technology can extend the shelf life of food material by storing them in raw material form rather than in final product form. The use of ultrasonic agglomeration to fuse particles together by shooting ultrasonic waves at them in 3DFP in the US Army, has been experimented to produce a wider variety of meals and thus offering more options to soldier's food. US Army also intended to create a 3D compact unit which can transform forage plant material such as tree, bark, barriers into food.

Elderly food

Many countries are facing with the aging problem, such as Japan, Sweden, and Canada. About 15%-25% of elderly people over the age of 50 and up to 60% of nursing home residues suffer from chewing and swallowing difficulties. People suffer from this disease are often provided with unappealing 'porridge-like food', which cause the loss of appetite and even nutritional deficiencies. To address this issue European Union (EU) has funded the performance project, aiming at designing an automated manufacturing method and offering personalized and specially textured food using 3D printing technology. Scientist in the project have created stimulated foods, such as peas, gnocchi, imitating their taste and texture. Not only the elderly foods will be fond of eating these foods, but also the soft, puree texture is easier for them to swallow. In, Germany a few nursing homes served a printed soft food to elderly suffering from chewing and swallowing difficulties. The tastier 3D-printed foods made of peas, mashed potatoes, and broccoli have successfully entered the market and 1000 of the country's agencies supply this type of food daily (Zhenmin *et al.*, 2017).

Confectionary markets

Sweets, accounting for a large proportion of the food market, are widely consumed in the World. Most of the leading companies and research centres of 3D food markets are focusing on sweets, such as Harshey, Choc Edge and 3D systems. One of the largest manufacturers of industrial grade 3D printers – 3D systems, cooperating with Harshey has developed an extrusion-based chocolate printer called Cacoethic can print various shapes in chocolate. The commercial chocolate printer called Cocreator, was designed by the scientist in the University of Exeter. Hans Fouche invented a 8 nozzle Cheetah chocolate 3D printer and used this system in experiment with different kinds of chocolates. Currently, most 3D chocolate is created using melt-extrusion based printer, while four students called 3D chocolatizing coming from University of Waterloo built a low-cost selective laser sintering based printers to create 3D chocolate structures using chocolate powder. The 3D system chef Jet pro is able to print both tasty and visually appealing sweets or food decorations using various kinds of food materials including sugar, chocolate and cheese.

Some proposals

3D FP is an emerging technology in food sector, we emphasize that the aspects as shown below should be kept in mind to achieve s successful printing. Rheological properties of food material is important to improve the printing performance and self-supporting ability in extrusion-based printing. The food material for extrusion printing should be pseudo plastic fluids with suitable shear-thinning behaviour and rapid structural recovery ability as it can be easily extruded out from the nozzle with the application of shear force and solidify rapidly again after leaving the nozzle. The binding mechanism, such solidification upon cooling, cross-linking mechanism, gel properties under different conditions (such as pH, ion, time, etc.) should be investigated to achieve desired properties suitable for 3D printing. Some additives like fat, blood plasma protein can be added to adjust the thermodynamic properties of material. The correlation between printing temperature and printing performance should be studied based on material's thermodynamic properties. As pretreatment methods (ultrasound, radio frequency etc) and post processing methods (drying, cooling, frying, etc) affect the gel formation mechanism and the stability of printed objects, the impact of post-processing and pretreatment methods should be studied, so as to determine the most suitable pretreatment and post-processing method (Zhenmin *et al.,* 2017).

Conclusion:

The Three-Dimensional Structure, or 3D Food Pinning Review, was primarily utilized with Dysphagia patients. What's more interesting is that printing allows for product customization for food. With the aid of plant-based materials (starch, pectin, and gelatine), the natural flavouring material can enhance the taste. Pectin, xanthan gum, and chitosan are sweeping agents for 3DFPT and can be used as binding agents. Its use is expanded to include the military, space, and confectionary industries.

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REVOLUTIONIZING HERBAL MEDICINES: ADVANCEMENTS IN ACTIVITY THROUGH NANOTECHNOLOGY

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Abstract:

Phytochemicals or secondary metabolites are compounds synthesized by plants, demonstrating diverse biological activities, and serving as a scientific rationale for incorporating herbs into traditional medicine. Despite being perceived as safe and cost-effective compared to synthetic drugs, herbal medicines encounter drawbacks such as low solubility, stability, and bioavailability, leading to potential degradation and diminished pharmacological efficacy. In recent years, there has been a growing interest in leveraging nanotechnology to enhance the performance of herbal drug formulations. Approaches utilizing nanotechnology-based delivery systems, characterized by biocompatibility, biodegradability, and composed of lipids, polymers, or nanoemulsions, offer promising solutions to address issues like solubility, stability, bioavailability, and overall pharmacological activity of herbal remedies. This review aims to provide an overview of the recent strides in developing nanotechnology-based herbal drug formulations for heightened efficacy, along with a discussion of the challenges faced by these delivery systems in the realm of herbal medicine.

Keywords: Nanotechnology; Herbal Medicine; Phytochemical; Drug Delivery.

Introduction:

The historical utilization of plants, whether in their direct form or as extracts, for medicinal purposes dates to ancient times. Plants serve as a rich source of diverse phytochemicals and have been harnessed for human health due to their minimal side effects, cost-effectiveness, and widespread acceptance among the general population. Phytochemicals, also known as secondary metabolites, are compounds produced by plants and play a crucial role in traditional medicine. These secondary metabolites have demonstrated a spectrum of biological activities, forming a scientific foundation for the incorporation of herbs in traditional medicinal practices. Their pharmacological effects extend to the treatment of bacterial and fungal infections, as well as addressing chronic degenerative conditions like diabetes and cancer. The global popularity of herbal medicines is on the rise, showing promising potential for offering treatment, maintaining, and enhancing health, and preventing/treating various diseases. This is attributed to their perceived safety compared to modern conventional medicines, along with their more economical nature [1].

Nevertheless, most of these biologically active phytochemical constituents face limitations. Primarily, their absorption and distribution are constrained, and the target specificity of these phytochemicals tends to be generally low, leading to diminished bioavailability and subsequently reduced biological activity. Furthermore, substantial doses are often necessary to elicit the activity of these phytochemical compounds. Additionally, certain phytochemical compounds are susceptible to acidic conditions, exhibiting low stability [2]. Nanotechnology-driven delivery systems serve as carriers for drugs, offering a solution to the various limitations faced by herbal medicines, including the enhancement of phytochemical bioavailability and bioactivity. The utilization of nanotechnology represents a promising and innovative approach applied to phytochemical constituents, ultimately increasing the efficacy of herbal medicines. Researchers aim to achieve the development of an efficient and safe drug delivery system, driving a renewed interest in herbal medicinal formulations due to recent advancements in nanotechnology. Various delivery system strategies, such as phytosomes, solid lipid nanoparticles (SLN), nanostructured lipid carriers (NLC), polymeric nanoparticles, nanoemulsions, among others, have been proposed. Nanoparticles have proven effective in modifying and improving the pharmacokinetic properties of diverse drugs, indicating the potential of the nanotechnology approach to heighten the bioavailability and bioactivity of herbal medicines [3]. This review seeks to provide an overview of the latest progress in the development of nanotechnology-based formulations for herbal drugs, aiming to enhance their overall activity.

Nanotechnology

The nanoscale system possesses a particle diameter of 0.1 μm, also referred to as submicrometer size. This presents several advantages across various aspects, including administration routes and heightened therapeutic effects, rendering it a more advanced and extensively researched field by scientists. Numerous studies have merged herbal medicine with nanotechnology due to the potential of nano-sized systems to enhance activity, reduce dosages, and mitigate side effects.

Herbal medicines employing nanotechnology-based delivery systems exhibit significant potential and distinctive properties, allowing the transformation of less soluble, poorly absorbed, and unstable substances into promising drugs. Consequently, nanotechnology-based delivery systems emerge as a promising avenue for augmenting herbal activity and addressing the challenges associated with herbal medicine (Figure 1) [4].

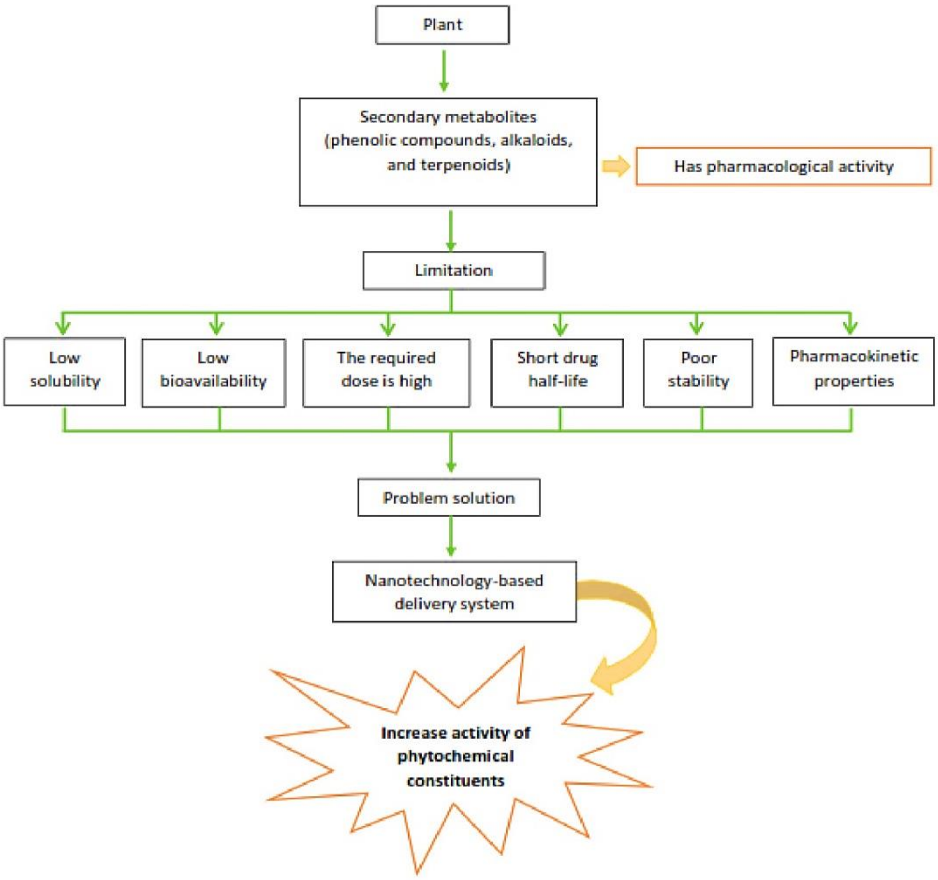

Figure 1: Illustration depicting the shortcomings of phytochemicals restricting their clinical utility. Nanotechnology-based delivery systems offer strategies to overcome these limitations, primarily by enhancing bioavailability and absorption, thereby amplifying their effectiveness.

Drug delivery system utilizing nanotechnology for phytochemical compounds

According to studies published, 70% of active ingredients obtained from plants are hydrophobic [5]. Innovative technology has been employed as a tactic to enhance the bioavailability and bioactivity of phytochemical compounds. The crucial aspect in developing new nanotechnology-driven treatments lies in the capability to design appropriate formulations for drug delivery. Efficient delivery of phytochemicals is vital for the successful prevention and treatment of diseases. Among these delivery systems are lipid-based and polymer-based formulations, showing potential to augment the bioactivity of phytochemical compounds [6].

Innovative nanotechnology-driven drug delivery systems have been created to enhance the efficacy of herbal drug delivery. Lipid-based carrier systems, encompassing vesicular structures like liposomes, phytosomes, transfersomes, niosomes, and ethosomes, as well as lipid particulates such as SLN and NLC, along with nanoemulsions, have attracted significant attention for delivering phytochemicals (Figure 2). These systems aim to boost the bioactivity and bioavailability, while also ensuring the stability of phytochemical compounds [5].

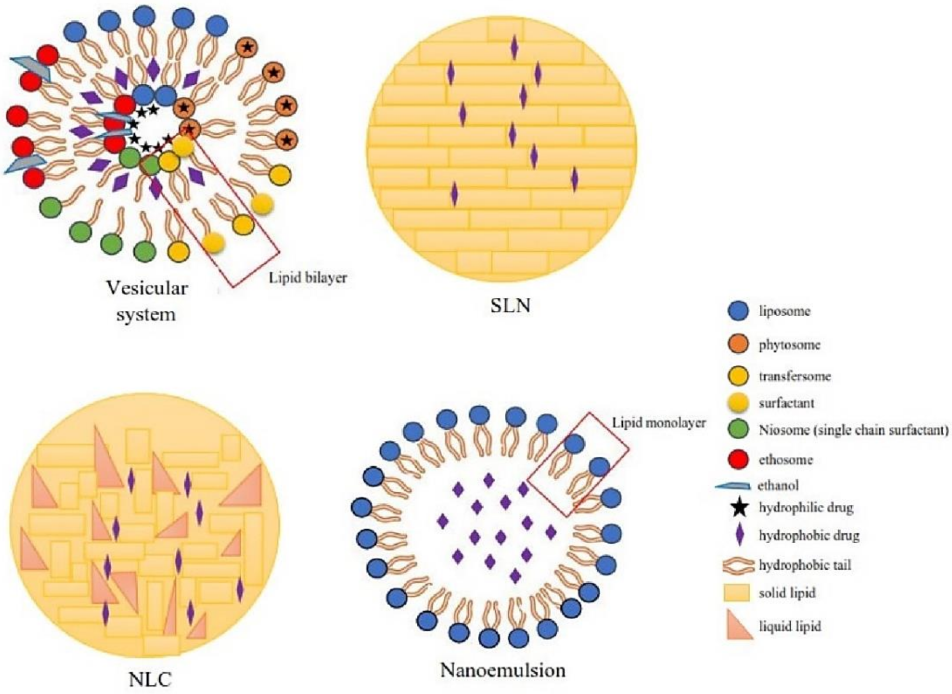

Figure 2: Categorization of the lipid-based delivery system.

Vesicular drug delivery systems can be described as well-organized structures comprising one or more concentric bilayers formed through self-assembly in the presence of water. SLN and NLC represent two nanoparticle systems characterized by lipid cores derived from solid lipids or combinations with liquid lipids [7]. Nanoemulsions are employed to enhance the bioavailability of hydrophobic drugs and those with high first-pass metabolism. The constituents of the nanoemulsion system encompass oils, lipids, surfactants, water-soluble cosolvents, and water.

Lipid-based nano systems stand out as the most extensively explored category of nanocarriers. In general, these carriers demonstrate reduced toxicity and more economical costs when compared to polymer carriers. One of the highly effective strategies in this category involves the delivery of liposomes and phytosomes. Liposomes, known for their exceptional biocompatibility and biodegradability, provide an opportunity to enhance the solubility, effectiveness, and bioavailability of drugs. They are versatile in encapsulating both hydrophilic and lipophilic drugs [8].

Polymers can serve as carriers for phytochemicals, giving rise to structures like dendrimers, micelles, polymersomes, and others. The accurate categorization of polymeric nanocarriers requires additional investigation, as specific limits are yet to be established in biomedical and pharmaceutical nanotechnology, leading to potential variations in perspectives. Nevertheless, a basic outline of polymer-based nanocarriers is illustrated in Figure 3 [9].

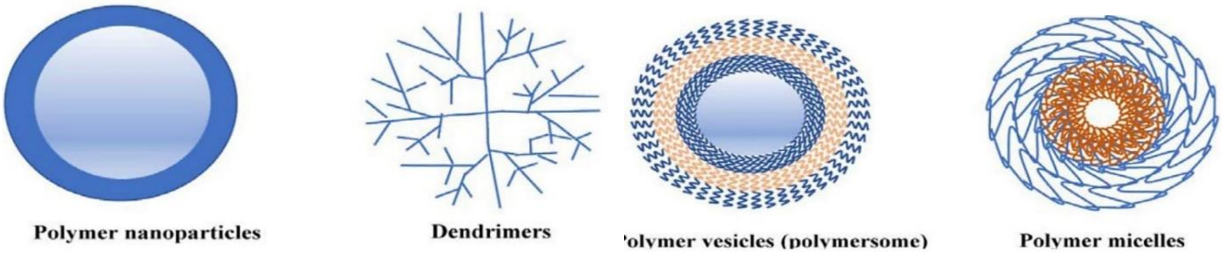

Figure 3: the categorization of polymeric nanocarriers [10]

Polymers have significantly contributed to the progress of drug delivery technology, facilitating the controlled release of active substances in a consistent dosage over an extended duration. The protection of drugs is achieved through encapsulation, entrapment within the core, conjugation, or adsorption onto the particle surface using polymers. Typically, natural polymers exhibit qualities of being non-toxic, biocompatible, and biodegradable. Among these, polysaccharides are frequently employed in the production of nanoparticles based on polymers [11].

Lipid-driven drug delivery systems, specifically phytosomes, have the potential to enhance the efficacy of phytochemical compounds. Phytosomes are a commonly employed delivery method to address challenges associated with phytochemicals, including low solubility, leading to suboptimal bioavailability and, consequently, diminished overall effectiveness.

Phytosomes serve as vesicular delivery systems designed to enhance the absorption and bioavailability of active ingredients characterized by low solubility. These structures consist of phospholipids and phytochemical constituents, forming hydrogen bonds by reacting the polar groups of phosphatidylcholines with plant extracts in aprotic solvents. The utilization of phytosome formulations has the potential to amplify the activity of phytochemical compounds derived from herbal plants [12].

Obstacles in the formulation of phytochemicals using nanotechnology

Delivery systems employing nanotechnology for active herbal ingredients present several advantages, including enhanced solubility, bioavailability, pharmacological activity, stability of active ingredients, protection against chemical and physical degradation, and reduced required dosage. The potential of herbal medicine development as a promising alternative cannot be ignored. However, nanotechnology-based formulations encounter challenges such as high production costs, difficulties in scaling up the process, and insufficient data on the safety and toxicity of herbal formulations using nanotechnology. Therefore, potential hazards associated with nanotechnology-based drug delivery systems need consideration. Another concern for nanoparticles is their stability, with issues arising regarding their ability to retain drugs, as some nanoparticles have demonstrated leakage upon contact with blood components. The production of nanosystems for phytochemicals incurs substantially greater costs, resulting in elevated retail prices. In European nations, the selection and funding of drugs from public sources are based on rational criteria, where elevated production costs pose a considerable hindrance. In such countries, nanomedicines with high price tags face minimal prospects of entering the market and reaching patients [13].

Conclusions:

The implementation of nanotechnology-driven delivery systems for phytochemical constituents holds significant importance in global public healthcare. The utilization of herbal medicines is expanding on a global scale; however, their drawbacks, including low solubility, limited bioavailability and pharmacological activity, and susceptibility to physical and chemical instability and degradation, restrict their clinical applicability. Hence, exploring nanotechnology-based delivery systems for herbal medicines emerges as a potential strategy to enhance their pharmacological effectiveness. Nevertheless, further scrutiny of these nanotechnology-based delivery systems is essential, particularly in terms of safety and toxicity profiles, to ensure their effectiveness and safety in treating various diseases.

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ROLE OF NANOTECHNOLOGY IN GREEN CHEMISTRY

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Abstract:

Nanotechnology has emerged as a promising field in green chemistry due to its potential in creating sustainable and environmentally friendly solutions. By harnessing the unique properties of nanomaterials, researchers have been able to develop innovative approaches for minimizing waste, reducing energy consumption, and enhancing the efficiency of chemical processes. This chapter provides an overview of the latest advancements in nanotech applications within the realm of green chemistry, highlighting key research findings and their implications for the future. Additionally, case studies and examples demonstrate how nanotechnology is being integrated into various industrial sectors to promote greener practices and mitigate environmental impact. From replacing volatile organic solvents with nanomolecules to developing recyclable catalysts and improving energy efficiency in synthesis, nanotechnology is revolutionizing the field of green chemistry. The utilization of nanomaterials in green chemistry has shown significant potential in addressing environmental challenges and promoting sustainability in various industries. In addition to the reduction of waste and energy consumption, nanotechnology offers opportunities for the development of efficient and eco-friendly chemical processes. This is achieved through the design and implementation of nanostructures with specific properties that enable targeted and precise applications. Furthermore, the integration of nanotechnology into industrial practices has paved the way for the creation of more sustainable products and processes, ultimately contributing to a greener and more environmentally conscious future.

Keywords: Nanotechnology, Green chemistry, Nanomolecules, Sustainability

Introduction:

Green chemistry aims to develop chemical processes and materials that are environmentally friendly and sustainable. By minimizing or eliminating the use and generation of hazardous substances, green chemistry offers a solution to the environmental impact caused by traditional chemical practices (Aithal & Aithal, 2021).

Nanotechnology, with its ability to manipulate materials at the molecular and atomic scale, has opened up a new frontier in the field of green chemistry. The potential of nanomaterials to revolutionize chemical processes and promote sustainability has garnered significant interest from researchers and industry professionals alike (Ciambelli *et al.*, 2020). This chapter aims to explore the latest developments in the application of nanotechnology within the realm of green chemistry, shedding light on the innovative strategies and solutions that are shaping a more eco-friendly future (Dutta & Das, 2021). Through case studies and examples, this chapter will delve into the integration of nanotechnology across various industrial sectors, demonstrating its capacity to drive greener practices and reduce environmental impact (Ciambelli *et al.*, 2020). Moreover, by harnessing the unique properties of nanomaterials, researchers are increasingly finding ways to minimize waste, enhance energy efficiency, and develop eco-friendly chemical processes. This exploration will highlight how the utilization of nanotechnology is not only addressing environmental challenges but also opening doors to the creation of sustainable products and processes (Patwardhan *et al.*, 2018).

Nanoparticles have shown great promise in serving as catalysts for green chemical reactions. Their high surface area to volume ratio and unique catalytic properties make them ideal candidates for promoting environmentally friendly chemical processes. In recent years, researchers have made significant strides in developing nanoparticle-based catalysts that enable efficient and selective chemical transformations with minimal waste generation (Alshammari *et al.*, 2016).

One notable example of nanoparticle catalysis is the use of metal nanoparticles for the conversion of harmful pollutants into non-toxic byproducts. These nanoparticles can facilitate the degradation of organic pollutants in wastewater or air, leading to the purification of environmental resources. Additionally, the use of nanoparticle catalysts has shown potential in promoting selective chemical reactions, thereby reducing the formation of unwanted byproducts (Varma, 2012).

Furthermore, the recyclability of nanoparticle catalysts adds to their appeal in green chemistry. With proper design and engineering, nanoparticle catalysts can be recovered and reused, contributing to the overall sustainability of chemical processes (Pandey, 2018).

As the field of green catalysis continues to advance, the role of nanoparticles is expected to expand, offering solutions for cleaner and more sustainable chemical processes across various industries. Nanoparticles hold the potential to play a pivotal role in driving the transition towards greener catalytic technologies, ultimately contributing to a more sustainable and environmentally conscious future (Nasrollahzadeh *et al.*, 2021).

The principles of green chemistry

The principles of green chemistry extend to the extraction processes within various industries. Traditional extraction methods often involve the use of large quantities of organic solvents, which can have detrimental effects on both human health and the environment. However, the integration of nanotechnology in extraction processes offers a promising solution to these challenges (Varma, 2012).

Nanomaterials, with their unique properties and high surface area to volume ratio, have been utilized to develop more efficient and environmentally friendly extraction techniques. For instance, the use of nanostructured materials as adsorbents or membranes has shown potential in replacing conventional extraction solvents with greener alternatives. These nanomaterial-based extraction methods not only reduce the consumption of hazardous solvents but also enhance the selectivity and efficiency of the extraction process (Mulvihill *et al.*, 2011).

Moreover, the application of nanotechnology in extraction processes has led to the development of sustainable and cost-effective techniques for recovering valuable compounds from natural sources. By designing tailored nanomaterials with specific affinity towards target molecules, researchers have been able to achieve higher extraction yields while minimizing the use of organic solvents and reducing overall environmental impact (Jiang *et al.*, 2014).

As the demand for sustainable extraction practices grows, the integration of nanotechnology in green chemistry is poised to play a pivotal role in transforming traditional extraction processes. The advancements in nanomaterial-based extraction technologies not only offer a pathway to reducing the environmental footprint of extraction operations but also contribute to the development of more sustainable and eco-friendly practices within the industry.

Green chemistry and extraction process

The principles of green chemistry extend to the extraction processes within various industries. Traditional extraction methods often involve the use of large quantities of organic solvents, which can have detrimental effects on both human health and the environment. However, the integration of nanotechnology in extraction processes offers a promising solution to these challenges (Varma, 2012).

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Nanotechnology for sustainable packaging

The field of nanotechnology has shown great promise in advancing sustainable packaging solutions (Khan, 2019).

The integration of nanotechnology in the development of sustainable packaging materials is a significant step towards reducing the environmental impact of the packaging industry. Traditional packaging materials often contribute to plastic waste and environmental pollution. (Yuan & Ozcan, 2015). However, by leveraging the unique properties of nanomaterials, researchers and industry professionals are exploring innovative solutions to create sustainable and eco-friendly packaging options.

Nanotechnology offers opportunities to enhance the barrier properties, mechanical strength, and biodegradability of packaging materials. Nanostructured coatings and films can be applied to conventional packaging substrates to improve their resistance to moisture, gases, and external impacts, thus extending the shelf life of packaged products. Furthermore, the incorporation of biodegradable nanomaterials in packaging production contributes to the development of environmentally sustainable alternatives to traditional non-biodegradable plastics (Jiang *et al.,* 2014).

In addition to enhancing the functional properties of packaging, nanotechnology enables the creation of intelligent and active packaging systems. Nanosensors embedded in packaging materials can provide real-time monitoring of product quality and integrity, thereby reducing food wastage and ensuring consumer safety. Moreover, the controlled release of antimicrobial or antioxidant nanomaterials within the packaging matrix can help prolong the shelf life of perishable goods while minimizing the need for chemical preservatives (Reig *et al.,* 2014).

The utilization of nanotechnology in sustainable packaging aligns with the principles of green chemistry by promoting the efficient use of resources, reducing waste, and addressing environmental concerns within the packaging industry. As research and development in this area progress, the application of nanotechnology is expected to drive the transition towards more sustainable and environmentally friendly packaging solutions (Huang *et al.,* 2018).

Importance of green chemistry with nanotechnology

Nanotechnology and green chemistry are two innovative fields that hold great potential for the development of sustainable and environmentally friendly products and processes. When combined, these two fields can lead to even more impactful and revolutionary solutions for a wide range of industries.

One of the key areas where the integration of green chemistry and nanotechnology is particularly promising is in the development of nanomaterials. These materials have the potential to significantly reduce the environmental impact of various industries, ranging from energy production to healthcare (Helland & Kastenholz, 2008).

By leveraging the principles of green chemistry, such as the design of safer chemicals and more sustainable processes, in conjunction with the unique properties of nanomaterials, it is possible to create products with minimal environmental impact. This can lead to the development of cleaner energy sources, more efficient catalytic converters, and enhanced drug delivery systems, among many other applications (Ciambelli *et al.*, 2020).

Furthermore, the implementation of green nanotechnology can also lead to the reduction of hazardous by-products and waste, as well as the conservation of energy and resources. By focusing on the principles of sustainability and environmental stewardship, the integration of green chemistry with nanotechnology can pave the way for a more sustainable and prosperous future. In today's rapidly changing world, the significance of green chemistry and nanotechnology cannot be overstated (Yuan & Ozcan, 2015). The potential of green chemistry and nanotechnology extends beyond just the development of sustainable products and processes. They also offer the opportunity to address pressing global challenges such as climate change, pollution, and resource depletion. By delving deeper into the integration of green chemistry and nanotechnology, researchers have found that these fields hold the potential to revolutionize various sectors, from agriculture to electronics and beyond (Aithal & Aithal, 2021).

In the agricultural sector, the use of nanotechnology in tandem with green chemistry principles can lead to the development of eco-friendly pesticides and fertilizers. These innovative solutions can minimize the environmental impact of traditional agricultural practices and contribute to sustainable food production.

Moreover, in the electronics industry, the marriage of green chemistry and nanotechnology can pave the way for the production of energy-efficient devices with minimal environmental repercussions. This could lead to a significant reduction in electronic waste and contribute to the conservation of resources (Gehrke *et al.,* 2015).

The ramifications of the synergy between green chemistry and nanotechnology also manifest in the field of water purification. Nanomaterials, when coupled with green chemistry practices, can result in the development of efficient and cost-effective water treatment technologies, contributing to the global challenge of providing clean and safe water for all.

The convergence of green chemistry and nanotechnology not only presents solutions for a sustainable future but also fosters innovation and economic growth. As the world continues to face complex environmental and societal challenges, the integration of green chemistry with nanotechnology stands as a beacon of hope for a more sustainable and prosperous future. The integration of green chemistry and nanotechnology has the potential to revolutionize various sectors, from agriculture to electronics and beyond. In the agricultural sector, the use of nanotechnology in tandem with green chemistry principles can lead to the development of eco-friendly pesticides and fertilizers. By leveraging the unique properties of nanomaterials and incorporating green chemistry practices, researchers and scientists can work towards minimizing the environmental impact of traditional agricultural practices and contributing to sustainable food production (Ozcans., 2015).

Furthermore, in the electronics industry, the marriage of green chemistry and nanotechnology can pave the way for the production of energy-efficient devices with minimal environmental repercussions. This could lead to a significant reduction in electronic waste and contribute to the conservation of resources. The potential applications of green nanotechnology in electronics range from more efficient batteries and energy storage solutions to novel materials for sustainable electronic devices, driving a shift towards a more environmentally conscious approach to electronics manufacturing (Mulvihill *et al.,* 2011).

The ramifications of the synergy between green chemistry and nanotechnology also manifest in the field of water purification. Nanomaterials, when coupled with green chemistry practices, can result in the development of efficient and cost-effective water treatment technologies, contributing to the global challenge of providing clean and safe water for all. By delving deeper into the integration of green chemistry and nanotechnology in water purification, researchers and engineers can work towards solving critical issues related to water scarcity and contamination, ultimately leading to the provision of clean water for communities around the world (Ciambelli *et al.,* 2020).

Conclusion:

The convergence of green chemistry and nanotechnology not only presents solutions for a sustainable future but also fosters innovation and economic growth. As the world continues to face complex environmental and societal challenges, the integration of green chemistry with nanotechnology stands as a beacon of hope for a more sustainable and prosperous future, offering promising solutions for diverse industries and global challenges (Ndukwu *et al.*, 2020).

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NANOCARRIERS FOR NOSE TO BRAIN DELIVERY

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Abstract:

The exploration of innovative drug delivery systems has gained significant momentum in recent years, particularly in addressing the challenges associated with treating neurological disorders. This chapter delves into the intricate realm of "Nanocarriers for Nose-to-Brain Delivery," a burgeoning field at the intersection of nanotechnology and pharmaceutical sciences. The nasal route offers a non-invasive and direct pathway to the central nervous system, presenting a promising avenue for overcoming the formidable challenges posed by the blood-brain barrier. The chapter commences with an elucidation of the fundamental principles of nanocarriers, setting the stage for a detailed exploration of the physiological intricacies of the nasal cavity. It delves into the advantages of nasal drug delivery, emphasizing its non-invasive nature and potential for circumventing the blood-brain barrier, thereby facilitating rapid onset of therapeutic action. A comprehensive survey of various nanocarriers employed in nose-to-brain drug delivery follows, encompassing liposomes, nanoparticles, micelles, dendrimers, and solid lipid nanoparticles. Formulation strategies are discussed, shedding light on surface modification techniques and sustained release approaches that enhance the penetration and retention of nanocarriers within the nasal mucosa. In synthesizing the current state of knowledge on nanocarriers for nose-to-brain delivery, this chapter aims to provide a comprehensive resource for researchers, clinicians, and pharmaceutical scientists, offering insights into the intricate landscape of drug delivery to the central nervous system.

Keywords: Nasal to brain delivery, Nanocarriers, Enhanced permeasion, Bioavailability

Introduction:

Nanocarriers refer to nano-sized structures designed to transport and deliver therapeutic agents, such as drugs or imaging agents, to specific cells or tissues in the body. These carriers are typically composed of nanoscale materials, including polymers, lipids, or proteins, and are engineered to encapsulate and protect the payload. The small size of nanocarriers allows them to navigate biological barriers, enhance drug stability, and improve the pharmacokinetics of the loaded substances. Nanocarriers play a crucial role in the field of nanomedicine, offering targeted and controlled drug delivery. By exploiting the unique properties of nanomaterials, these carriers can improve the solubility, bioavailability, and therapeutic efficacy of drugs. Additionally, they enable the possibility of site-specific drug release, reducing side effects and enhancing the overall treatment outcome [1,2].

Delivering drugs to the brain is a complex task due to various physiological and anatomical challenges. The central nervous system is protected by several barriers that restrict the passage of substances, including drugs, from the bloodstream to the brain tissue. Some key challenges in drug delivery to the brain are as follows [3-6]:

Blood-Brain Barrier (BBB): The BBB is a highly selective barrier formed by specialized endothelial cells that line the blood vessels in the brain. This barrier restricts the passage of many drugs, preventing them from reaching therapeutic concentrations in the brain.

Limited permeability: The tight junctions between endothelial cells in the brain capillaries limit the permeability of drugs. Many drugs, even those that can cross other tissues easily, face challenges in penetrating the BBB.

Efflux transporters: Efflux transporters actively pump drugs out of the brain, reducing their concentration. These transporters, such as P-glycoprotein, can contribute to drug resistance and limit the effectiveness of treatment.

Large molecular size: Many potential therapeutic agents, including proteins and gene-based therapies, have large molecular sizes that hinder their ability to cross the BBB.

Metabolic enzymes: Enzymes in the blood and brain can metabolize drugs, reducing their concentration before they reach the intended target.

Rapid clearance: The brain has a rapid clearance mechanism that can quickly remove substances from the cerebrospinal fluid, limiting the time drugs have to exert their effects.

Intranasal delivery challenges: While intranasal delivery is an attractive route for bypassing the BBB, challenges include achieving uniform drug absorption, avoiding mucociliary clearance, and ensuring adequate drug distribution within the brain.

Heterogeneity of brain diseases: The diversity of diseases affecting the brain adds complexity to drug delivery. Different neurological disorders may have distinct challenges that need to be addressed for effective treatment.

Physiology of the nasal cavity

The physiology of the nasal cavity is a critical aspect to consider in the context of drug delivery, especially for intranasal administration. The nasal cavity serves various functions, including the filtration, humidification, and warming of inspired air, as well as olfaction. In the context of drug delivery, understanding the nasal physiology helps in designing effective delivery systems. Here are key aspects of the physiology of the nasal cavity [7,8]:

Nasal anatomy:

Nasal septum: The nasal cavity is divided into left and right halves by the nasal septum, which is made up of bone and cartilage.

Turbinates (Conchae): Protruding structures on the lateral walls of the nasal cavity that help increase the surface area for air contact.

Nasal vestibule: The anterior part of the nasal cavity, just inside the nostrils.

Nasal mucosa:

Respiratory epithelium: Lines the majority of the nasal cavity and is composed of ciliated pseudostratified columnar epithelial cells.

Olfactory epithelium: Located in the upper part of the nasal cavity, containing olfactory receptors involved in the sense of smell.

Goblet cells: Secrete mucus to trap particles and microorganisms, aiding in the protection of the respiratory epithelium.

Blood supply and vascularization:

The nasal cavity is highly vascularized, with a rich blood supply. Blood vessels in the nasal mucosa contribute to the absorption of drugs.

Nasal Secretions:

Mucus produced by goblet cells and serous glands helps trap particles, microorganisms, and potentially drugs, influencing drug absorption.

The mucociliary clearance mechanism involves the coordinated movement of cilia on the epithelial cells, helping to clear mucus and trapped particles toward the pharynx.

Nasal Blood-Brain Barrier (BBB):

The nasal epithelium is considered a part of the BBB. It poses a barrier to the entry of certain substances into the brain.

Tight junctions between epithelial cells contribute to the selective permeability of the nasal mucosa.

Lymphatic drainage:

The nasal cavity has a network of lymphatic vessels that play a role in draining interstitial fluid and immune responses.

Temperature and humidity regulation:

The nasal cavity helps in conditioning inhaled air by warming and humidifying it before it reaches the lower respiratory tract.

Advantages of nasal drug delivery

Nasal drug delivery offers several advantages, making it an attractive route for administering therapeutic agents. These advantages are particularly significant in the context of certain medical conditions and drug formulations. The advantages of nasal drug delivery are as follows [9]:

Non-invasive administration:

Nasal drug delivery is non-invasive, avoiding the use of needles or invasive procedures. This makes it more patient-friendly, reducing discomfort and the risk of infection associated with other administration routes.

Rapid onset of action:

Drugs administered through the nasal route can exhibit rapid onset of action. The nasal mucosa has a rich blood supply, allowing for direct absorption into the bloodstream, and avoiding the first-pass metabolism in the liver.

Avoidance of first-pass metabolism:

Unlike oral administration, which involves passage through the gastrointestinal tract and liver (first-pass metabolism), drugs delivered nasally bypass the hepatic metabolism, leading to higher bioavailability.

Improved patient compliance:

Nasal drug delivery is often more convenient for patients, especially when compared to injections or oral medications. This convenience can improve patient compliance with the prescribed treatment regimen.

Suitability for peptides and proteins:

The nasal mucosa allows for the absorption of peptides and proteins, which may be degraded in the gastrointestinal tract. This is particularly relevant for certain biopharmaceuticals.

Brain targeting (Nose-to-Brain delivery):

The nasal route provides direct access to the central nervous system, allowing for nose-to-brain delivery. This is advantageous in the treatment of neurological disorders as it facilitates the delivery of drugs to the brain bypassing the blood-brain barrier.

Potential for self-administration:

Nasal drug delivery is often simple enough for self-administration, enabling patients to manage their medications independently.

Reduced systemic side effects:

Targeted delivery to the nasal mucosa can help reduce systemic side effects associated with some medications, as the drug is localized to the site of action.

Emergency situations:

Nasal drug delivery can be useful in emergency situations where prompt drug delivery is crucial, as it offers a quick and accessible route.

Improved bioavailability:

Certain drugs may have higher bioavailability when administered through the nasal route, leading to increased therapeutic efficacy.

Potential for prolonged drug release:

Formulation strategies can be employed to achieve sustained or prolonged drug release from nasal formulations, providing a controlled therapeutic effect over time.

Types of nanocarriers for nose to brain delivery

Several types of nanocarriers have been explored for nose-to-brain drug delivery, each with unique properties that can be tailored to specific therapeutic needs. These nanocarriers aim to overcome the challenges associated with delivering drugs to the central nervous system by exploiting the nasal route. Some common types of nanocarriers for nose-to-brain delivery [10,11]:

Liposomes:

Liposomes are vesicular structures composed of lipid bilayers. They can encapsulate both hydrophilic and hydrophobic drugs. Surface modifications with ligands can enhance their interaction with nasal mucosa, facilitating drug delivery to the brain.

Nanoparticles:

Nanoparticles, often made from polymers or biodegradable materials, are solid colloidal particles with sizes ranging from 1 to 1000 nm. They offer versatility in drug encapsulation and can be designed to release drugs in a controlled manner. Examples include polymeric nanoparticles and lipid nanoparticles.

Micelles:

Micelles are self-assembling colloidal structures formed by amphiphilic molecules. In the context of nose-to-brain delivery, micelles can encapsulate hydrophobic drugs and improve their solubility. Surface modifications can enhance their stability and targeting capabilities.

Dendrimers:

Dendrimers are highly branched macromolecules with a defined structure. Their multivalent nature allows for efficient drug loading, and their surface can be modified to improve drug release and targeting. Dendrimers have shown promise in enhancing drug permeability across the nasal mucosa.

Solid Lipid Nanoparticles (SLNs):

SLNs are submicron-sized lipid particles that offer advantages such as biocompatibility and controlled drug release. They can be formulated with various lipids to optimize drug delivery to the brain through the nasal route.

Nanoemulsions:

Nanoemulsions are oil-in-water or water-in-oil dispersions with droplet sizes in the nanometer range. They offer enhanced drug solubility and stability and can be used for efficient nose-to-brain drug delivery.

Polymeric nanogels:

Nanogels are hydrogel nanoparticles that can encapsulate drugs and provide sustained release. Their three-dimensional structure and tunable properties make them suitable for nose-to-brain drug delivery.

Nanostructured Lipid Carriers (NLCs):

NLCs are lipid-based nanocarriers with a structured lipid matrix. They combine the advantages of solid lipid nanoparticles and liquid lipids, offering improved drug loading and release characteristics.

Nanocrystals:

Nanocrystals consist of drug particles at the nanoscale, enhancing their solubility and bioavailability. They can be incorporated into nasal formulations to improve drug delivery efficiency.

These nanocarriers are continually being researched and developed to optimize their properties and address specific challenges associated with nose-to-brain drug delivery, including overcoming the blood-brain barrier and achieving targeted and sustained drug release within the central nervous system.

Formulation strategies

Surface modification for enhanced penetration

Surface modification for enhanced penetration from the nose to the brain is crucial in developing effective intranasal drug delivery systems for neurological disorders. The blood-brain barrier poses a significant challenge to drug delivery, and surface modification strategies aim to improve the transport of drugs across this barrier. Some formulation strategies for enhancing penetration from the nose to the brain [12-15]:

Nanoparticle formulations

Liposomes and nanoliposomes:

Encapsulating drugs in liposomes or nanoliposomes can improve their bioavailability and penetration. Surface modification with ligands such as transferrin or angiopep-2 can enhance receptor-mediated transport across the blood-brain barrier.

Polymeric nanoparticles:

Utilizing biocompatible polymers such as polyethylene glycol (PEG) or chitosan can improve the stability and mucoadhesive properties of nanoparticles. Functionalizing the surface with ligands for receptor-mediated endocytosis can enhance penetration.

Surface coating and modification

PEGylation: Coating nanoparticles with polyethylene glycol (PEG) reduces opsonization and improves circulation time, allowing for increased chances of crossing the blood-brain barrier.

Cationic Polymers: Positively charged polymers like chitosan can interact with negatively charged mucosal surfaces, enhancing mucoadhesion and facilitating nasal absorption.

Surface Charge Modification: Modifying the surface charge of nanoparticles can influence their interaction with mucosal membranes. Generally, neutral or slightly negative charges are preferred to minimize repulsion from the negatively charged mucosal surface.

Incorporation of penetration enhancers

Surfactants:

Non-ionic surfactants such as polysorbate 80 or Tween 80 can enhance drug solubility and permeation across mucosal membranes.

Chelating Agents:

EDTA (ethylenediaminetetraacetic acid) or citric acid can be used as chelating agents to open tight junctions and improve drug penetration.

Targeting Ligands

Receptor-mediated targeting:

Incorporating ligands specific to receptors on the blood-brain barrier, such as transferrin or insulin, can facilitate receptor-mediated transport.

Cell-Penetrating Peptides (CPPs): Utilizing peptides that have the ability to penetrate cell membranes can enhance drug delivery to brain cells.

Mucus-penetrating particles

Mucus penetration enhancers:

Incorporating enzymes or mucolytic agents like dextranase can help particles overcome the mucus barrier, improving penetration.

Mucoadhesive formulations

Mucoadhesive formulations play a crucial role in enhancing drug delivery from the nose to the brain by increasing the residence time on the nasal mucosa. Several strategies and components commonly used in mucoadhesive formulations for intranasal drug delivery [16,17]:

Polymers with Mucoadhesive Properties

Chitosan:

Chitosan is a natural cationic polymer with mucoadhesive properties. Its positive charge allows interaction with negatively charged mucosal surfaces.

Carbopol:

Carbomers, such as Carbopol 934, are synthetic polymers that can form gels and exhibit mucoadhesive properties. They enhance drug residence time in the nasal cavity.

Hydroxypropyl Methylcellulose (HPMC):

HPMC is a cellulose derivative known for its bioadhesive properties. It can be used to form a gel matrix that adheres to the nasal mucosa.

Polyvinyl Alcohol (PVA):

PVA is a water-soluble polymer that can contribute to the mucoadhesive properties of a formulation.

Polyethylene Glycol (PEG):

PEG can be used in combination with other polymers to improve the flexibility and mucoadhesive properties of the formulation.

Thiolated polymers

Thiolated chitosan:

Modification of chitosan with thiol groups enhances its mucoadhesive properties through disulfide bond formation with mucin proteins in the mucus.

Liposomes and nanoparticles

Cationic liposomes:

Liposomes with cationic surfactants or lipids can interact with the negatively charged mucosal surface, providing mucoadhesive properties.

Polymeric nanoparticles:

Nanoparticles with mucoadhesive polymers, such as chitosan or thiolated polymers, can improve adhesion to mucosal membranes.

Incorporation of mucoadhesive excipients

Mucin and mucin analogs:

Incorporation of mucin or mucin analogs in formulations can enhance mucoadhesion by mimicking the natural interactions with mucosal surfaces.

Hydrophilic polymers:

Addition of hydrophilic polymers, such as polyvinylpyrrolidone (PVP) or polyethylene glycol (PEG), can improve mucoadhesive properties.

Gelling agents

Poloxamers and poloxamines:

These thermoreversible polymers can form gels at nasal temperatures, providing sustained drug release and mucoadhesion.

Gellan gum:

Gellan gum is a polysaccharide that forms gels and exhibits mucoadhesive properties. It can be used to improve the viscosity of the formulation.

pH-sensitive formulations

pH-responsive polymers:

Formulations that change their pH upon contact with nasal mucosa can enhance mucoadhesion. pH-sensitive polymers, such as polyacrylic acid, can be considered.

Nasal spray devices

Metered dose nasal spray:

Appropriate nasal spray devices with suitable droplet size and distribution can optimize the delivery of mucoadhesive formulations [18].

Incorporation of Penetration Enhancers

Surfactants:

Non-ionic surfactants like polysorbate 80 can be included to enhance drug solubility and permeation while maintaining mucoadhesive properties.

Safety and toxicity considerations

The biocompatibility of nanocarriers for nose-to-brain delivery is a critical aspect that must be thoroughly investigated to ensure the safety and efficacy of intranasal drug delivery systems. Consideration of potential safety and toxicity issues is crucial during the design, development, and evaluation of nanocarriers. Some key considerations for assessing the biocompatibility of nanocarriers for nose-to-brain delivery:

- Cytotoxicity Studies
- Hemocompatibility
- Immunotoxicity
- Histopathological Examination
- Biodistribution Studies
- Genotoxicity Assessment
- Metabolism and Clearance
- Stability Studies
- Endotoxin Levels
- Batch-to-Batch Consistency

- Long-term and Chronic Toxicity Studies
- Inflammatory Response
- Species-Specific Considerations
- Regulatory Compliance

Regular and rigorous safety assessments throughout the development process will help identify and address potential issues, ensuring the biocompatibility of nanocarriers for nose-to-brain delivery. Collaboration with toxicologists, pharmacologists, and regulatory experts is crucial to navigating the complex landscape of safety evaluation for nanomedicines.

Conclusion:

In summary, the future of nose-to-brain delivery holds immense potential for transforming the landscape of neurological therapeutics. By addressing the challenges, exploring innovative technologies, and fostering interdisciplinary collaboration, researchers and clinicians can pave the way for the development of safe, effective, and patient-friendly drug delivery strategies for a wide array of neurological disorders.

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BANANA PEEL EXTRACT MEDIATED NOVEL METHOD FOR THE SYNTHESIS OF SILVER NANOPARTICLES AND ITS CHARACTERIZATION

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Abstract:

The current study reports a novel, non-toxic, cost-efficient, eco-friendly, easy and rapid method for the synthesis of Ag-Nps using banana peel extract (BPE) as a reducing and capping agent. Boiled, crushed, acetone precipitated, air-dried peel powder was used for reducing silver nitrate. Silver nanoparticles were formed when the reaction conditions were altered with respect to pH, BPE content, concentration of silver nitrate and incubation temperature. The colorless reaction mixtures turned brown-yellow and displayed UV–visible spectra characteristic of silver nanoparticles. The different factor affecting silver reduction was investigated. The optimum conditions were silver nitrate, BPE and incubation time. BPE can reduces silver ions into silver nanoparticles within 5 min after heating the reaction mixture (40-100 ^{0}C) as indicated by the developed brown-yellow color. Fourier transform infra-red spectroscopy (FTIR) indicated the role of different functional groups (isocyanates, sulfur, carboxyl, amine and hydroxyl) in the synthetic process. Silver nanoparticles were characterized. X ray diffraction revealed their crystalline nature. The average size of nanoparticles was 30 nm as determined.

Keywords: Silver nanoparticles, Agricultural waste banana peel, characterization.

Introduction:

The term "Nano" is derived from the Greek word which means dwarf and the particles size is around 1 to 100 nm. The nanotechnology is one of the most vigorous research areas of interdisciplinary research especially material science, biotechnology [1]. The nanotechnology field has been called as the future industrial revolution which based on the synthesis of nanomaterials which particle size between 1 to 100 nm. The nanotechnology entails the synthesis of nanoparticles reveals different shapes, sizes and morphology. The nanotechnology is a multitalented subject which deals with chemistry, biology, physics and engineering [2]. Nanotechnology became an interesting area of study in medicine due to simplicity of loading drugs, competence in functionalization, latent for targeted delivery, tumor-homing nature, tumor-locating capability, diagnostic capability, therapeutic potential, etc [3-5]. Nanomaterials turned into an entrancing subject of concentrate in medication because of simplicity of stacking drugs, capability in functionalization, potential for designated conveyance, cancer homing nature, growth finding ability (optic/attractive), analytic ability, restorative potential, etc [6]. Thus of these properties, alongside the proof of clinical and preclinical examinations, numerous nanoproducts including bio-inserts, drug conveyance frameworks, drug items, beauty care products, filters, biomarkers, imaging specialists, biosensors, tissue designing platforms, etc were marketed with the objective of working on the nature of human existence [7]. Then again, a few examinations into broadened collaborations of nanomaterials (metal, metal-oxide, ceramic, composite) inside the body have uncovered a specific degree of poisonous reactions [8-9].

Banana plant is considered as the largest herb in the world, and it is cultivated in various developing countries. Banana is measured as the mainly vital source of vigor. 100 g of edible part of banana supplies about 89.0 KCal of energy, 1.1 g protein, 385.0 mg potassium, 8.0 mg calcium, 1.0 mg sodium, 0.11 mg copper, 30.0 mg magnesium, 121.8 g carbohydrates, 0.40 mg iron, 11.7 mg vitamin C, 610 μg niacin (vitamin PP), 40 μg thiamine (vitamin B1) and 23.0 μg folic acid [10]. By tradition banana is utilized for the cure of cardiac diseases, gout, diabetes, intestinal lesions in ulcerative colitis, inflammation, nephritis, diarrhea, dysentery, hypertension, in sprue, uremia, pain and snakebite [11,12,13]. The banana plant root is used in blood disorders, venereal diseases [12], and as anthelmintic [13]. Ash of banana leaves is applicable in eczema [14] and as cool dressing for blister and burns [12]. Stem juice is utilized for cure of cholera, otalgia, haemoptysis, diarrhea and dysentery. Flower of banana plant is applicable in menorrhagia, diabetes and dysentery [12].

Recently, green synthesis of Ag NPs had gained so much attention in developed countries due to development insists of environmental friendly technology for metal synthesis. Green chemistry methods are more effective because ecofriendly, nontoxic and cheap. Biosynthesis methods are more important because of their other conventional method such as physical, chemical methods and to avoid the hazardous byproducts [15]. Silver nanoparticles (AgNPs) are progressively utilized in numerous fields including medical, food, healthcare, consumer, and industrial medical, food, healthcare, consumer and industrial purposes, due to their unique physical and chemical properties. The specific properties exhibited by nanoparticle are also used in the enhancement of decimation of tumors [16]. All over the world, bananas are consumed, after consumption of the pulp, the peels are generally discarded [17]. Banana and Plantain peels are key farming wastes which is utilized as animal feeds, medicine, soap making, Blacking of leathers, fillers in rubber and so on [18]. A some functions of banana peels are discussed in the literature consists exploitation as a biosorbent for heavy metal removal [19], use as a substrate for generating fungal biomass [20], development for their medicinal properties [21], in ethanol fermentation [22], utilize in the production of laccase [23]. Banana peel is an source of phenolic compounds which considered a rich source of antioxidants for food against cancer and heart disease [24]. The banana peel contains numerous antioxidant compounds, such as gallocatechin [24] and dopamine [25].

As per the literature survey, we assumed that banana peels that are intrinsically wealthy in polymers such as lignin, hemicellulose and pectins [26] could be utilized in the synthesis of silver nanoparticles. The present study aims to demonstrate a previously unreported green biological route for the synthesis of silver nanoparticles using an banana peels extract and characterized by UV–visible spectroscopy, FTIR analysis and X-Ray diffraction. Besides, their antimicrobial activity has also been discussed.

Materials and Methods:

1. Banana Peels Extract (BPE) preparation:

Banana (*Musa paradisiaca*) peels were washed and boiled in distilled water for 10 to 20 min. The peels (50 g) were crushed in 100 ml distilled water and the extract was filtered through Whatman filter paper to remove insoluble fractions and macromolecules. This filtrate was treated with equal volume of chilled acetone and the resultant precipitate was centrifuged at 1000rpm for 15 min. This precipitate was resuspended in distilled water and stored in refrigerator room temperature for further studies. This extract was used as reducing as well as stabilizing agent [27].

Figure 1: Banana Peels Extract (BPE) preparation

2. Synthesis of silver nanoparticles using BPE:

1mM aqueous solution of silver nitrate ($AgNO_3$) was prepared and used for the synthesis of Silver nanoparticles, 30 ml of Banana peels fruit extract was added into 90 ml of aqueous solution of 1mM silver nitrate for reduction into Ag ions and kept at room temperature for 5 hours to 15 hours [28].

Figure 2: Synthesis of silver nanoparticles using BPE

3. Observation of silver nanoparticles with change in colours:

The fresh Banana peels solution was prepared by taking 50 g of thoroughly washed and finely cut peels in a 250 mL glass beaker along with 100 mL of distilled water and then boiling the mixture for 10 to 20 min before finally decanting it [29]. The extract was filtered through Whatman filter paper no 1 and stored at room temperature and could be used within 5hour. The filtrate was treated with aqueous 1 mM $AgNO_3$ solution in an flask and test tube and incubated at room temperature. As a result, a brown-yellow solution was formed, indicating the formation of silver nanoparticles. Its hawed that aqueous silver ions could be reduced by aqueous extract of Banana fruits peels parts to generate extremely stable silver nanoparticles in distilled water observe in following image [30].

Figure 3: Silver nanoparticles

Result and Discussion:

1. UV spectroscopy:

Silver nanoparticles appear brown in color in aqueous medium as a result of surface of plasm on vibration. In previous studies similar color change was observed. Synthesis of silver nanoparticle in sterile distilled water was confirmed by using UV spectrophotomer in a range of wavelength from 370 to 349 and 284 nm. As an *Musa paradisiaca* peel (Banana peels) extract was mixed in aqueous solution of silver ion the reduction of pure silver ions to silver nanoparticles was confirmed by measuring UV-spectrum of their action media. The UV absorption spectrum of silver nanoparticles in the peel extract is shown in graph. The spectroscopic band of silver nanoparticles solution was found to be close 0.080 nm which confirms the synthesis of silver nanoparticles. The absorption strongly depends on the particle size chemical surrounding and dielectric medium.

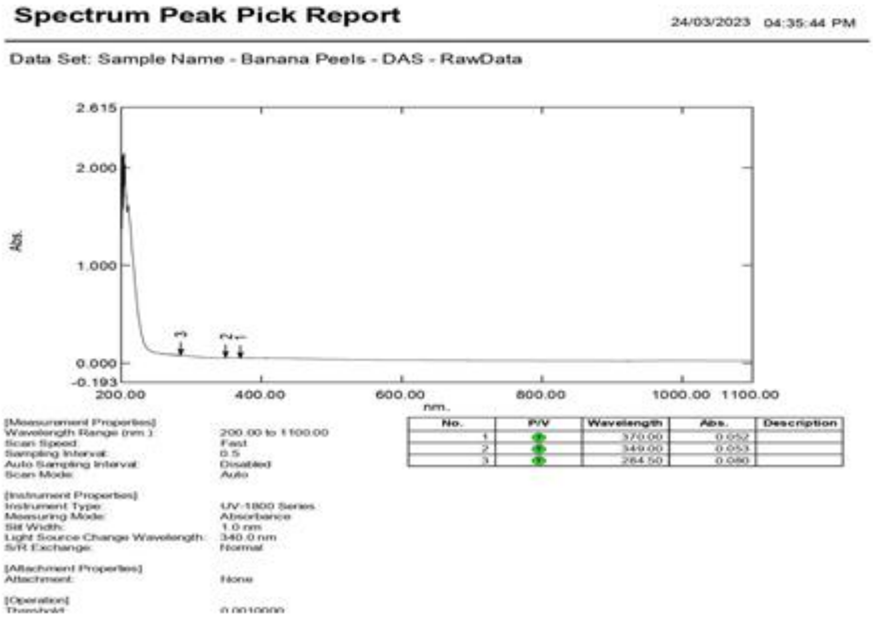

Figure 4: UV spectroscopy

2. FTIR analysis:

To find out the functional groups on banana peel extract and forecast their role in the synthesis of silver nanoparticles, FTIR analysis was performed. There was shifts in the following peaks- A peak at 3395.83 cm-1 is result from the stretching of alcohols and phenol (O-H) group and the absorption peak at 2929.03 cm-1 could be due to (C-H) stretching of alkane functional group. The absorption peak at 2398.59 cm-1 could be due to O-H and NH3 stretching of amino acid functional group. The absorption peak at 2147.83 cm-1 could be due to N=C=O stretching of isocyanates (R-N=C=O) functional group. The absorption peak at 1641.49 cm-1 could be due to C-C stretching of aromatic C-C group.

The absorption peak at 1532.51 cm^{-1} could be due to N-H in plane bending stretching of RNH_2 amines and their salts functional group. The absorption peak at 1406.17 cm^{-1}could be due to functional group. The absorption peak at 1093.69 cm^{-1} could be due to C=S stretching of C=S sulfur compounds. The absorption peak at 824.60 C-O-C asymmetrical stretching of ether and epoxide functional group. The absorption peak at 580.60 could be N-H stretching of secondary amide functional group. Banana peels extract are mainly involved in reduction of silver ions to silver nanoparticles. In IR spectra of synthesized silver nanoparticles bands of absorbance around bands are matching to plant extract IR spectrum. This denotes from fruits extract may responsible for reduction and stabilization of silver ions to silver nanoparticles.

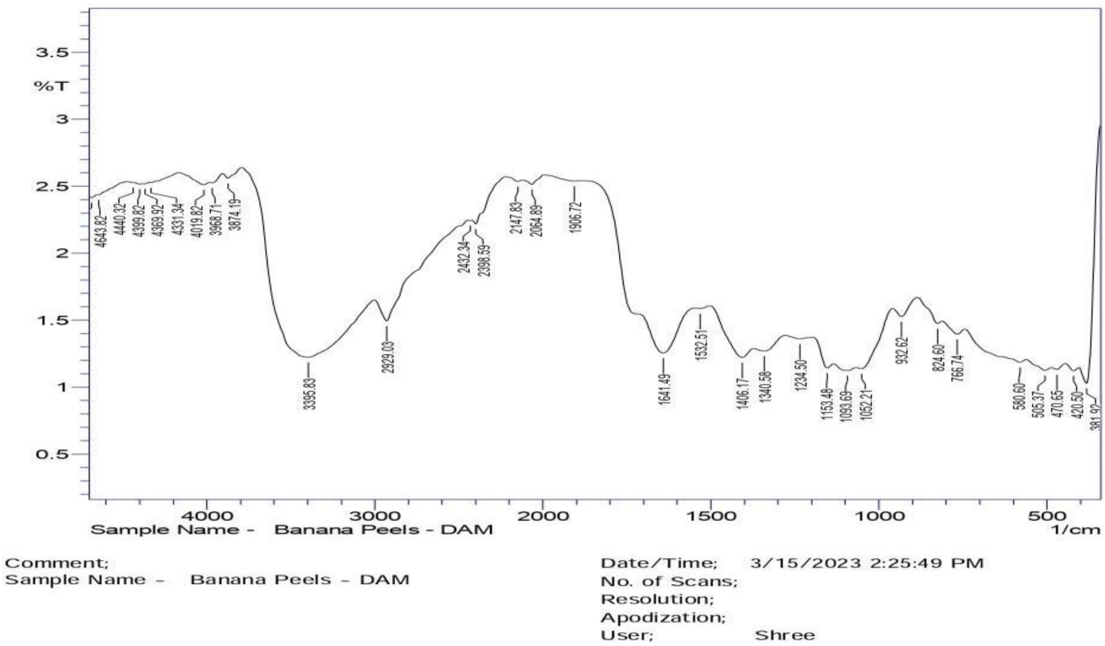

Figure 5: FTIR analysis

3. X-Ray Diffraction:

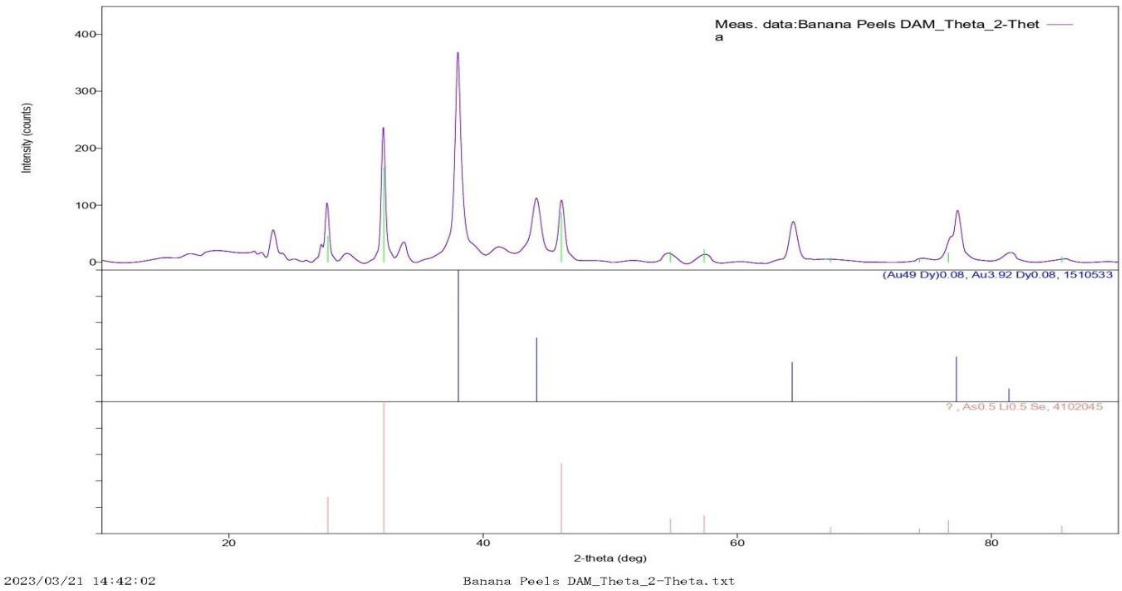

Figure 6: X-ray diffraction

The crystalline nature of silver nanoparticles was further confirmed by X-ray diffraction (XRD) analysis. X-ray diffraction is used to characterize crystallographic structure, grain size, and preferred orientation in polycrystalline or powder solid samples. The XRD patterns of synthesized AgNPs are shown in Fig.6 and 7. Silver nanoparticles synthesized from Banana peel extract showed Bragg Reflection peaks at 38.05, 44.23, 64.33, 77.25, 81.39 and 97.68 in the 2h range between 10–80 which can be indexed to the (111), (200), (220), (311), (222), (400) planes of face centered cubic (fcc) crystal, respectively. They have a good match with the standard diffraction pattern of JCPDS No. 89-3722, revealing that the synthesized silver nanoparticles are composed of pure crystalline silver and the particle size is approximately 30 nm. The peak corresponding to (111) plane is more intense than the other planes, suggesting that the (111) plane is in the predominant orientation.

PDF Card No. : 1510533 Quality:C

Sub-File Name:
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Name: (Au49 Dy)0. 08 I/Ic (RIR)= 26. 14
Crystal System: Space Group: F m -3 m(225) Dmeas:
Cell Parameters: a= 4. 0926 b= 4. 0926 c= 4. 0926
Alpha= 90. 000 Beta= 90. 000 Gamma= 90. 000
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Reference:
Radiation: Wavelength=
2Theta range: 38. 05 - 97. 68
Database comments:
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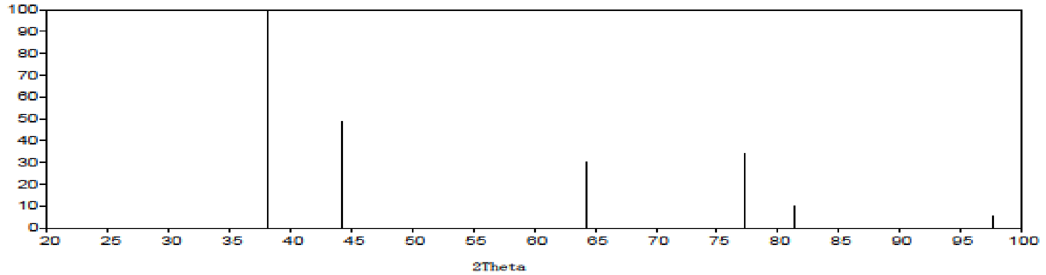

No.	2Theta	d-Value	Intensity	h	k	l	No.	2Theta	d-Value	Intensity	h	k	l
1	38. 05	2. 363	100. 0	1	1	1							
2	44. 23	2. 046	48. 4	2	0	0							
3	64. 33	1. 447	29. 9	2	2	0							
4	77. 25	1. 234	34. 1	3	1	1							
5	81. 39	1. 181	9. 8	2	2	2							
6	97. 68	1. 023	5. 1	4	0	0							

Note: 2theta are calculated with wavelength = 1. 54059
2023/03/21 14:42:27 1/1

Figure 7: X-ray diffraction

Conclusion:

To conclude, we have utilized unreported banana peels as agricultural waste material was successfully utilized for the consistent and quick synthesis of silver nanoparticles. These reaction mixtures exhibited typical colors and UV–visible spectra characteristic of silver nanoparticles. The structures produced by this novel, cost-effective, non-toxic, ecofriendly,

Abundantly available banana peels agricultural waste materials were characterized by a variety of standard analytical techniques. They are crystalline, uniform, and spherical and mono dispersed nanoparticles with average particle size of 30 nm.

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RESEARCH AND REVIEWS IN NANOTECHNOLOGY

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Abstract:

Nanotechnology is a rapidly evolving interdisciplinary field that involves manipulating matter at the nanoscale, typically at dimensions less than 100 nanometers. The impact of nanotechnology spans various scientific disciplines and industries, including materials science, physics, chemistry, biology, and engineering. In this comprehensive discussion, we will delve into key aspects of nanotechnology research and reviews, exploring recent advancements, applications, challenges, and the future prospects of this exciting field. Nanotechnology has slowly yet deeply taken over different industries worldwide. This rapid pace of technological revolution can especially be seen in the developed world, where nano-scale markets have taken over rapidly in the past decade. Nanotechnology is not a new concept since it has now become a general-purpose technology. Four generations of nanomaterials have emerged on the surface and are used in interdisciplinary scientific fields; these are active and passive nanoassemblies, general nanosystems, and small-scale molecular nanosystems.

Recent advancements in nanotechnology

Nanotechnology provides a link between classical and quantum mechanics in a gray area called a mesoscopic system. This mesoscopic system is being used to manufacture nanoassemblies of nature such as agricultural products, nanomedicine, and nanotools for treatment and diagnostic purposes in the medical industry (McNeil, 2005). Diseases that were previously untreatable are now being curtailed via nano-based medications and diagnostic kits. This technology has greatly affected bulk industrial manufacturing and production as well. Instead of manufacturing materials by cutting down on massive amounts of material, nanotechnology uses the reverse engineering principle, which operates in nature. It allows the manufacturing of products at the nano scale, such as atoms, and then develops products to work at a deeper scale (de Charles and Owens, 2003).

Worldwide, millions and billions of dollars and euros are being spent in nanotechnology to utilize the great potential of this new science, especially in the developed world in Europe, China, and America Schulte (2005). However, developing nations are still lagging behind as they are not even able to meet the industrial progression of the previous decade (Lemley, 2005). This lag is mainly because these countries are still fighting economically, and they need some time to walk down the road of nanotechnology. However, it is pertinent to say that both the developed and developing world's scientific communities agree that nanotechnology will be the next step in technological generation (Salamanca-Buentello *et al.*, 2005). This will make further industrial upgrading and investment in the field of nanotechnology indispensable in the coming years.

With advances in science and technology, the scientific community adopts technologies and products that are relatively cheap, safe, and cleaner than previous technologies. Moreover, they are concerned about the financial standing of technologies, as natural resources in the world are shrinking excessively (Roco, 2011). Nanotechnology thus provides a gateway to this problem. This technology is clear, cleaner, and more affordable compared to previous mass bulking and heavy machinery. Moreover, nanotechnology holds the potential to be implemented in every aspect of life. This will mainly include nanomaterial sciences, nanoelectronics, and nanomedicine, being inculcated in all dimensions of chemistry and the physical and biological world (Singh, 2017). Thus, it is not wrong to predict that nanotechnology will become a compulsory field of study for future generations (El Naschie, 2017). This review inculcates the basic applications of nanotechnology in vital industries worldwide and their implications for future industrial progress (Waldron, 2006).

Nanomaterials

Nanomaterials play a pivotal role in nanotechnology, exhibiting unique properties compared to bulk materials. Carbon-based nanomaterials such as graphene and carbon nanotubes have garnered significant attention due to their exceptional mechanical, electrical, and thermal properties. Additionally, the development of advanced nanocomposites and nanostructured materials has opened new possibilities in various industries (Novoselov *et al.,* 2004).

Nanomaterials are substances that are, or have been, reduced in size to the range from 1 nm to ~ 100 nm (i.e. 1 to ~ 100 nanometers, or 1 to ~ 100 × 10-9 meters). Nanotechnology is the science and applications of nano-materials, and is growing at an ever increasing pace. At this particle size the properties of materials can be altered dramatically. Properties such as solubility, reactivity, spectroscopy, electrical and magnetic, transport through membranes etc. are generally different from those of the same materials with large particle size. The applications of materials of nano size have escalated in the last fifteen or so years and are currently gaining momentum. The technology has broad applications in performance materials, health, consumer products, water, information technology and energy. The discovery of fullerenes and of Graphene is very important factors in the development of nanotechnology. Not very many nanomaterials have so far been included in chemical catalogues of commercially available substances, e.g. as compared with catalysts (although some catalysts are now available as nanoparticles), hence the relatively smaller size of this chapter. Fullerenes and related materials such as carbon nanotubes have found applications in medicine for the transport of drugs and biological materials to targeted sites and some readily available derivatives are described in this chapter, together with other commercially available nanoparticulate substances, e.g. catalysts, magnetic and electrically conducting thin films, and quantum dots. General safety aspects of handling nanomaterials have been briefly addressed. Nanoscience and nanotechnology is developing explosively as the awareness and usefulness of materials at the nano scale is becoming evident.

Nanomedicine

Nanotechnology has revolutionized the field of medicine, leading to the emergence of nanomedicine. Nanoparticles are employed for drug delivery, imaging, and diagnostics, offering targeted and controlled release of therapeutic agents. The integration of nanotechnology in healthcare has the potential to transform treatments, improving efficacy while minimizing side effects (Peer, 2007). Nanomaterials play an important role in drug delivery nowadays. Quick and accurate disease detection, improved treatment, and augmented prophylaxis are the great contributions of nanomaterials in the fields of health and pharmaceuticals. However, various nanomaterials have been linked to different toxicological effects in living systems. Thus humans and animals are at a greater danger of toxic insults due to nanomaterials. Nanomaterials may affect different organs of living systems following exposure. Reversible or irreversible damage may occur, depending upon the nature of the nanomaterials, degree of exposure, dose and frequency of nanomaterial exposure. The underlying mechanisms of toxicity include free radical production, inflammation, and DNA damage. This chapter focuses on in vitro and in vivo toxicity implications of nanomaterials with particular emphasis on toxicological insults in different organs. However, the lack of generalized in vivo models and the variable physicochemical properties of nanomaterials pose a great hindrance in the evaluation of nanomaterial-induced toxicity concerns. In this chapter we have discussed the interaction of nanomaterials with biological and cellular systems, the toxic implications of nanomaterials for vital systems of the body (nervous system, liver, kidney, skin), and the underlying pathological phenomena behind these toxic interactions (Wilfred, 2022).

This level of control is achieved through the utilization of scanning probe microscopes, which enable scientists to observe and manipulate matter at the nanoscale. By employing these tools, researchers can carefully position and arrange atoms and molecules to build complex structures, exploiting their unique properties and interactions. One of the fundamental concepts in MNT is self-assembly, where molecules are designed to spontaneously arrange themselves into desired structures through specific chemical interactions. This principle mimics natural processes, such as DNA replication, and allows for the creation of intricate nanoscale architectures with minimal human intervention. Self-assembly holds immense potential for the production of nanoscale components, such as transistors, sensors, and drug delivery systems, in a cost-effective and scalable manner. Molecular nanotechnology has the potential to revolutionize medicine by enabling targeted drug delivery, early disease detection, and regenerative medicine. Nanoparticles can be designed to carry drugs directly to diseased cells, minimizing side effects and maximizing therapeutic efficacy. Furthermore, nanosensors can detect biomarkers indicative of diseases at their earliest stages, allowing for timely intervention. Tissue engineering and regenerative medicine also benefit from the precise manipulation of molecules, as researchers can create scaffolds and structures that mimic the body's natural tissues. The relentless demand for faster, smaller, and more efficient electronic devices has spurred research in molecular nanotechnology. Nanoscale components, such as transistors and memory devices, can be fabricated with unparalleled precision, leading to the development of ultra-high-density integrated circuits. Molecular electronics, which involve the construction of circuits at the atomic level, offer the potential for significantly faster and more energy-efficient devices. Molecular nanotechnology presents opportunities for sustainable energy generation and storage. For instance, advanced nanomaterials can enhance the efficiency of solar cells, enabling the harnessing of sunlight for clean energy production. Nanoscale catalysts also hold promise for efficient energy conversion and storage systems, such as fuel cells and batteries. Additionally, nanotechnology-based water purification techniques offer the potential to address the global water scarcity crisis by enabling efficient removal of contaminants. Molecular nanotechnology has revolutionized materials science by providing access to new materials with enhanced properties. By manipulating the arrangement of atoms and molecules, researchers can create materials that exhibit exceptional strength, flexibility, and conductivity. Carbon nanotubes, for example, possess remarkable electrical and mechanical properties and find applications in diverse fields, including electronics, aerospace, and medicine

Applications of nanotechnology

Electronics and photonics

Many electronic devices have been miniaturized to a much smaller scale than their original predecessors. For many electronic devices, miniaturizing electronic components (batteries, circuits, etc.) to the micron and then the nano level has been enough to reduce the device's overall size while keeping its efficiency high. However, devices that use optical components are inherently trickier to miniaturize and enhance because the materials used within them need to be very high quality, and the devices themselves need to be incredibly precise. Over the last decade or so, the use of nanomaterials in optic and photonic devices has significantly increased, and they are now present in everything from optical coatings on lenses to photodetectors, light polarizers, and many more.

Many different properties of nanomaterials enable them to absorb, reflect, and manipulate light to perform the desired effect. These have been exploited for a range of optical and photonic devices as well as devices that use optical components. The nanomaterials' inherent small size enables the components and devices they are used in to be smaller than bulkier counterparts. In addition to the small size, the high active surface area of many nanomaterials can be exploited to manipulate and change the properties of light. As many optical components are used in electronic devices, those that perform both an optical and an electronic function, such as optoelectronic devices also require highly conductive materials. Many nanomaterials have very high electrical conductivities that can be utilized. The abrasion resistance and toughness of many nanomaterials are also useful. This helps prevent delicate optical components from becoming damaged, which in turn changes the optical efficiency of the components.

One other significant aspect of nanomaterials in optic and photonic technologies is that they exhibit strong light-matter interactions, ensuring that the optical components efficiently interact with light. Many nanomaterials also exhibit a broad optical response and fast relaxation times, and some are efficient enough to be used in terahertz technologies. Even when the optical components remain nanosized—meaning they are used as stand-alone nano components instead of part of a bigger component—they can be easily integrated with other bulkier optical components. Nanomaterials in optical components range from complete devices that rely on their optical properties to function to components that are used in non-optical devices and to optical coatings used to both protect and enhance the optical properties of the device.

Lenses are used within many electronic devices and large-scale technologies. Lenses are typically too large to be wholly made of nanomaterials. However, nanostructures of different materials can be incorporated into different lenses to improve the optical performance and toughness of the lens. One of the more common options for lenses is to use nanomaterial-based coatings (or specific thin films for higher-tech applications), which also improves the performance and abrasion resistance/toughness of the lens, without needing to directly incorporate the nanomaterial in the lens. This approach is less expensive, as standard lenses can be used that are of much lower cost. Small amounts of coating are often not too costly. Moreover, the use of coatings can introduce specific effects to the lens, such as anti-reflective properties.

Basic lenses don't usually require nanomaterials, the use of nanostructures within lenses—and coatings/thin films—can, aside from basic performance and optical clarity enhancements, drastically alter the properties of the lens. One of the more common ways is to turn a lens into a highly effective optical filter or optical polarizer, both of which are used in a range of technologies. A few other specific applications of nanomaterials include optical cavities, saturable absorbers, and optical switches for ultrafast lasers, as well as in complementary metal-oxide-semiconductor sensors, optical biosensors for detecting various biomolecules, and wearable optic technologies. Many of the areas of optics and photonics overlap because they both deal with light, although there are some specific areas where nanomaterials are only used in photonic applications such as in the processing and sensing of light, rather than in the manipulation of light that concern many optical components.

Design engineers can incorporate photonic nanostructures into different lenses as well. Like many nanomaterial-enhanced optical lenses, photonic nanostructures improve the performance of microscopes. Another big area of nanophotonics is in photodetectors because the electromagnetic absorption properties of many nanomaterials lead to highly efficient photodetectors, which are used in many technologies, including computers. Moreover, because many nanomaterials have a broad absorption spectrum, these photodetectors can detect ultraviolet (UV), infrared (IR), and photons of visible light. Nanomaterials have been used to create a range of components within fiber optic cables. These include optical filters and Bragg gratings, which are either used on their own within fiber optic cables or to build other components, such as fiber optic anemometers. Many nanomaterials are used to build different parts of fiber optic cables because they interact strongly with the propagating light. Other areas where nanomaterials are used to create photonics-based devices include fiber optic rectennas to convert electromagnetic waves into an electric current, more advanced magnetic recording devices, and ways of improving the light intensity in spectroscopy and solar cell technologies, to name a few.

Optical and photonic technologies have advanced recently, but the need for highly precise components makes their improvement more challenging than many other technologies. In recent years, however, a wide range of nanomaterials have been used due to their strong interaction with light and their ability to manipulate the properties of light. Thus, many more technologies are being developed that use high-tech nanomaterial optics and photonic components. The semiconductor industry has embraced nanotechnology for the development of smaller, more efficient electronic devices. Nanoscale transistors, quantum dots, and nanophotonics are key areas of research, promising faster and more energy-efficient electronic components (Cui, 2001).

Energy storage and conversion

In the face of escalating energy demands and concerns over environmental sustainability, the quest for efficient and clean energy sources has become paramount. Nanotechnology, with its ability to manipulate matter at the nanoscale, has emerged as a promising solution in the field of energy harvesting and storage. By harnessing the unique properties of nanomaterials, researchers are unlocking new avenues for renewable energy generation and revolutionizing energy storage systems. Nanotechnology offers diverse ways to harvest energy from renewable sources. One notable example is the utilization of nanoscale photovoltaic materials, such as quantum dots and perovskites, in solar cells. These materials exhibit exceptional light-absorbing capabilities, enabling higher power conversion efficiencies and reducing production costs. Additionally, nanostructured electrodes, such as nanowires and nanotubes, enhance the surface area of photovoltaic devices, further enhancing their performance

Another area where nanotechnology is making significant strides is in thermoelectric energy conversion. Nanostructured materials with engineered phonon and electron transport properties enable efficient conversion of waste heat into usable electricity. By manipulating the size, shape, and composition of nanomaterials, researchers are achieving unprecedented improvements in thermoelectric efficiency, offering new possibilities for energy harvesting from industrial processes, vehicles, and even the human body. Energy storage is a critical component for a sustainable and reliable energy infrastructure. Nanotechnology is revolutionizing this field by improving the performance and durability of energy storage devices, such as batteries and super capacitors. Nanomaterials, such as graphene and carbon nanotubes, exhibit high surface areas and exceptional electrical conductivity, enabling faster charge-discharge rates and increased energy densities in batteries. Moreover, nanoscale engineering allows for the design of electrode architectures with enhanced ion and electron transport, leading to longer cycle life and improved overall performance.

Nanotechnology also plays a pivotal role in the development of super capacitors, offering a high-power alternative to batteries. Nanomaterials, such as metal oxides and conducting polymers, provide a large surface area and efficient charge storage mechanisms, resulting in rapid energy storage and release. Additionally, the integration of nanoscale architectures, such as nanowires and nanosheets, further enhances the performance of super capacitors by facilitating ion diffusion and minimizing internal resistance. Beyond batteries and super capacitors, nanotechnology is exploring novel energy storage concepts. For instance, nanomaterials-based hydrogen storage systems hold promise for clean and efficient energy storage. Metal hydrides, carbon nanotubes, and nanoporous materials can store hydrogen at high densities, enabling its use as a versatile and environmentally friendly energy carrier (LiX *et al.*, 2018). While nanotechnology has demonstrated remarkable potential in energy harvesting and storage, several challenges need to be addressed. The scalability of nanomaterial synthesis, cost-effectiveness, and long-term stability remain critical areas of research and development. Additionally, the potential environmental and health impacts of nanomaterials necessitate a comprehensive understanding and rigorous safety protocols. Looking ahead, the future of nanotechnology in energy harvesting and storage appears promising. Continued research and collaboration among scientists, engineers, and policymakers will pave the way for innovative nanomaterials, efficient energy conversion devices, and sustainable energy storage systems. As nanotechnology continues to mature, it holds the key to unlocking the full potential of renewable energy sources and ushering in a cleaner and more sustainable energy future (Li and Lee, 2022).

Nanotechnology has contributed to advancements in energy storage and conversion technologies. Nanomaterials, such as nanowires and nanocomposites, are being explored for high-performance batteries and efficient solar cells, addressing the growing demand for clean and sustainable energy solutions (Arico *et al.,* 2005).

Challenges and considerations

Safety and toxicity

Despite the promising applications, concerns about the safety and toxicity of nanomaterials persist. Understanding the potential health and environmental impacts of nanotechnology is crucial for responsible development and deployment (Nel *et al.*, 2006).

Concerns with safety regarding the use of nanotechnology have arisen primarily from the recognition of several unique attributes of nanoparticles:

- The ultra small particle size permits the particles to be carried deeply into tissues – particles may be deeply respired into the lungs; may pass through the blood-brain barrier; or translocate between organs
- The molecular structure of nanoparticles and the relatively greater surface area confer on these particles different chemical reactivities than for larger structures made from the same elements or molecules.

Some evidence suggests that nanoparticles may be more toxic to tissues than larger molecular structures. In addition to concerns about toxicity of nanoparticles that are inhaled, ingested, or absorbed through dermal exposure during initial contact, nanoparticle waste may present a hazard in the environment.

Nearly any substance can be toxic at a high enough dose, the more relevant question is: how toxic are nanomaterials at the potential concentrations at which they might be used? Any toxic effects of nanomaterials will be specific to the type of base material, size, shape and coatings. However, to determine and understand the toxic effects of nanomaterials, strategies and interpretation of the data must be done correctly and assumptions taken into consideration. In toxicity studies of nanoparticles, different research groups used different cell lines, culturing conditions, and incubation times. With our understanding about the nature of nanoparticles during toxicity test, it is difficult to compare results from different research groups and determine whether the cytotoxicity observed is physiologically relevant. Many biological models, including cells in culture, aquatic organisms including embryonic zebrafish (Danio rerio), and whole-animal tests such as rodents, currently are used to determine potential toxicological effects of chemicals. In urban atmospheres, diesel- and gasoline-fueled vehicles and stationary combustion sources have for many years contributed particulate materials throughout a wide size range including nanomaterials. The toxic effects of such particles are still being investigated with regulatory concerns moving from the traditional particles less than 10 μm in aerodynamic diameter and below. Experimental results indicate that increased toxicity of finer-sized particles. However, to determine and understand the toxic effects of nanomaterials, strategies and interpretation of the data must be done correctly and assumptions taken into consideration. The range of nanotechnology products is very extensive and they can be broken down into a number of different compound classes, including metals, metal oxides, carbon, and semiconductor nanomaterials. The following discussions will be based on nanomaterial classes.

The most immediate challenge in nanotechnology is that we need to learn more about materials and their properties at the nanoscale. Research institutions across the world are rigorously studying how atoms fit together to form larger structures. We're still learning about how quantum mechanics impact substances at the nanoscale. Because elements at the nanoscale behave differently than they do in their bulk form, there's a concern that some nanoparticles could be toxic. Some doctors worry that the nanoparticles are so small, that they could easily cross the blood-brain barrier, a membrane that protects the brain from harmful chemicals in the bloodstream. If we plan on using nanoparticles to coat everything from our clothing to our highways, we need to be sure that they won't poison us.

Closely related to the knowledge barrier is the technical barrier. In order for the incredible predictions regarding nanotechnology to come true, we have to find ways to mass produce nano-size products like transistors and nanowires. While we can use nanoparticles to build things like tennis rackets and make wrinkle-free fabrics, we can't make really complex microprocessor chips with nanowires yet. There are some hefty social concerns about nanotechnology too. Nanotechnology may also allow us to create more powerful weapons, both lethal and non-lethal. Some organizations are concerned that we'll only get around to examining the ethical implications of nanotechnology in weaponry after these devices are built. They urge scientists and politicians to examine carefully all the possibilities of nanotechnology before designing increasingly powerful weapons.

If nanotechnology in medicine makes it possible for us to enhance ourselves physically, is that ethical? In theory, medical nanotechnology could make us smarter, stronger and give us other abilities ranging from rapid healing to night vision. Should we pursue such goals? Could we continue to call ourselves human, or would we become transhuman -- the next step on man's evolutionary path? Since almost every technology starts off as very expensive, would this mean we'd create two races of people -- a wealthy race of modified humans and a poorer population of unaltered people? We don't have answers to these questions, but several organizations are urging nanoscientists to consider these implications now, before it becomes too late.

Ethical and societal implications

Advances in nanotechnology are transforming the ways of creating materials and products, leading society to the threshold of a second industrial revolution. However, future opportunities will depend significantly on how nanotechnology stakeholders deal with the short-term and long-term benefits, limitations, uncertainties and risks of nanotechnology. They will be tasked with navigating a variety of new social and ethical challenges associated with areas such as privacy, the environment, energy, population, genetics, agriculture, food, and security.

The ethical implications of nanotechnology, including privacy issues, societal acceptance, and responsible research practices, require careful consideration. Engaging in open dialogue and adopting ethical frameworks is essential for the responsible growth of nanotechnology (Allhoff *et al.,* 2009).

Nanotechnology will have very broad applications across all fields of engineering, so it will be an amplifier of the social effects of other technologies. There is an especially great potential for it to combine with three other powerful trends – biotechnology, information technology, and cognitive science – based on the material unity of nature at the nanoscale and on technology integration from that scale. Technological convergence highlights such existing issues as the treatment of the disabled, communication breakdowns, economic stagnation, and threats to national security. Nanotechnology itself may possibly raise distinctive ethical and social issues in the future, but much of the public discussion to this point has been misdirected and misinformed, lacking a firm social scientific basis. Thus, it will be important to integrate social and ethical studies into nanotechnology developments from their very beginning.

Social scientific and economic research can help manufacturers and governments make the right decisions when deploying a new technology, maximizing its benefit for human beings. In addition, technically competent research on the societal implications of nanotechnology will help give policymakers and the general public a realistic picture free of unreasonable hopes or fears. The costs of premature or excessive regulation would be extremely high, harming the very people it was intended to protect, and failure to develop beneficial nanotechnology applications would be unethical.

The significance of nanotechnology depends largely on how its development relates to wider trends going on in the world such as the impending population declines of most advanced industrial nations, the apparent diminishing returns to increased medical research and health care investment, and the threatened deceleration of progress in microelectronics. Well established social-scientific explanations for unethical behavior – such as learning, strain, control, and subculture theories – could help us understand possible future cases in nanotechnology industries. Ethics and social implications are largely matters of social perception, and the public conception of nanotechnology is still in the early stages of developing. Social science can now begin to examine its unfolding impacts in all sectors of the economy, in most spheres of life, and both short-term and long-term time scales (Bainbridge, 2004).

Nanotechnology is a rapidly developing field that holds great promise for many different industries, but it also raises a number of ethical concerns. Some of the key ethical concerns surrounding nanotechnology include:

Environmental risks: Nanoparticles have unique physical and chemical properties that could lead to unintended consequences for the environment. For example, nanoparticles could enter the food chain and harm wildlife, or they could contaminate water supplies.

Health risks: Some nanoparticles have been found to be toxic to humans and other living organisms, raising concerns about their safety for use in consumer products, medical devices, and other applications.

Intellectual property issues: The development of nanotechnology is leading to a significant increase in the number of patents being filed, which could stifle innovation and limit access to the technology for those who need it most.

Job losses: The increasing use of nanotechnology in various industries could lead to job losses, particularly in manufacturing and other traditional industries that are being displaced by automation.

Social equity: The unequal distribution of resources and access to nanotechnology could exacerbate existing social inequalities and lead to a widening gap between the rich and the poor.

Regulation: There is a growing concern that the regulation of nanotechnology is not keeping pace with its rapid development, leading to a lack of oversight and accountability in the development and use of the technology.

These are just a few of the ethical concerns surrounding nanotechnology, and they highlight the need for continued public debate and discussions about the appropriate uses and applications of this rapidly evolving field. It's important for governments, industry, and society to work together to ensure that the benefits of nanotechnology are realized in a responsible and sustainable manner.

Future prospects

Molecular nanotechnology

Molecular nanotechnology also holds the promise of revolutionizing data storage, enabling higher capacity and more reliable storage media. Energy and Environment: Addressing the global energy and environmental challenges is a pressing concern. Molecular nanotechnology provides solutions in areas such as solar energy, energy storage, and water purification. Nanoscale materials, like quantum dots and nanowires, can enhance solar cell efficiency and make renewable energy more accessible. Nanomaterials with high surface area-to-volume ratios can improve energy storage devices, such as batteries and supercapacitors. Additionally, nanofilters and membranes offer effective methods for water purification and desalination.

Manufacturing and materials

The ability to manipulate matter at the molecular scale opens up exciting possibilities for advanced manufacturing. Molecular nanotechnology can enable the creation of novel materials with extraordinary properties, such as lightweight yet ultra-strong composites or superconducting materials for efficient energy transmission. Additive manufacturing techniques, including 3D printing at the nanoscale, hold the potential to revolutionize production processes and enable the fabrication of complex structures. As molecular nanotechnology continues to evolve, its impact on various industries will become increasingly significant. Researchers are exploring new materials, designing smarter nanodevices, and pushing the boundaries of what is possible at the molecular scale. However, challenges remain, including scalability, cost-effectiveness, and ethical considerations. One of the most exciting prospects is the concept of molecular nanorobots capable of performing precise tasks within the human body, such as targeted drug delivery or repairing damaged tissues. These nanorobots could revolutionize healthcare by providing personalized medicine and introducing innovative treatment approaches. Moreover, molecular nanotechnology can contribute to solving global challenges, such as clean energy production, water scarcity, and environmental sustainability. By harnessing the power of nanoscale engineering, we can develop more efficient and environmentally friendly solutions. Molecular nanotechnology represents a remarkable frontier that holds immense potential for transforming our world. By mastering the art of manipulating matter at the atomic and molecular levels, scientists and engineers are paving the way for groundbreaking advancements in medicine, electronics, energy, and manufacturing. As research progresses and technology advances, we can anticipate a future where molecular nanotechnology becomes an integral part of our daily lives, revolutionizing the way we live, work, and interact with the world around us. Molecular nanotechnology (MNT) is a field of scientific exploration and engineering that focuses on manipulating matter at the atomic and molecular scale. It encompasses the design, fabrication, and control of nanoscale structures and devices with unprecedented precision. By harnessing the principles of physics, chemistry, and biology, molecular nanotechnology offers tremendous potential for advancements in various fields, including medicine, electronics, energy, and materials science. This article delves into the fascinating world of molecular nanotechnology, exploring its principles, applications, and future prospects. At the core of molecular nanotechnology lies the ability to manipulate individual atoms and molecules to create functional structures and devices. Molecular nanotechnology holds the promise of precise control over matter at the atomic and molecular levels. The development of nanoscale machines and devices could revolutionize manufacturing, medicine, and computing (Drexler, 1986).

Nanotechnology in space exploration

Nanotechnology is poised to revolutionize space exploration by offering innovative solutions to the unique challenges faced in the extreme conditions of outer space. With the manipulation of materials at the nanoscale, space agencies and researchers are exploring several key applications. Nanomaterials are being employed in the development of lightweight and durable spacecraft components, enabling faster and more cost-effective space travel. Nanosensors are aiding in the monitoring of spacecraft health, detecting potential issues and ensuring mission success. Additionally, nanotechnology is enhancing energy storage solutions, making long-duration missions and solar power generation in space more efficient. As space exploration continues to expand, nanotechnology promises to play a pivotal role in advancing our understanding of the cosmos and expanding our capabilities beyond Earth's boundaries. The application of nanotechnology in space exploration is an exciting frontier. Nanomaterials and nanosensors could enhance spacecraft design, enable lightweight and durable materials, and contribute to advancements in space medicine (Roco *et al.*, 2013).

The convergence of nanotechnology knowledge and the vision to set foot on other planets are at a beneficial crossroads where knowledge supports the vision and the vision energizes the quest for that knowledge (Newberry, 2024).

Nanotechnology may hold a key role in making space travel more practical. Advancement in nanomaterials will lead to the development of lightweight solar space vehicles. By significantly reducing the amount of rocket fuel required, these advancements may lead to lowering the cost of reaching orbit and traveling in space. In addition, nanosensors and nanorobots could improve the performance of spaceships, space suits and the equipment used to explore planets and moon. Researchers are now looking into employing materials made from carbon nanotubes to reduce the weight of spaceships while retaining or even increasing structural strength. These carbon nanotubes can be used to make the cable needed for a space elevator. This space elevator can significantly reduce the cost of sending materials into orbit. This idea sounds good and nano carbon tubes certainly likely to give more intelligence and control for space technology.

Robots can perform well even in space technology. They are designed to handle the weather and tough terrains in space and can carry weight. They can repair damaged parts of the international space station by remotely operating by technologists from earth. But there are many new ideas coming into play when nanorobots began to work in space technology. Bio–nanorobots are greatly employed in space suits. These can respond to damages to space suits. This bio–nanorobots can even respond if the astronaut is in trouble. For example, they can provide drugs in a medical emergency.

Design, manufacturing, programming, and control of nanoscale robots for space applications may take place massively in the upcoming years. Nanorobots are smart structures capable of actuation, sensing, signaling, information processing, intelligence and swarm behaviour at the nanoscale. Nanorobots are invisible to the naked eye, which makes it difficult to manufacture it. Techniques like Scanning Electron Microscopy and Atomic Force Microscopy are being used to understand the molecular structure of these nanorobots. Virtual Reality is also great being used in the manufacture of bio – nanorobot. Bio -nanorobotics makes use of nanotechnology combined with important discoveries in molecular biology. In such robots, proteins, DNA could act as motors, mechanical joints, transmission elements or sensors. In space applications, these are mainly used in Networked Terra Xploring and All Terrain Xploring situations. This bio – nanorobot can protect astronauts from chemicals, radiations, temperature and pressure in space.

The network of nanosensors is required to search large areas of planets such as Maars for traces of water or other chemicals. For interplanetary missions, thruster systems are required. Use of nanoparticles could reduce the weight and complexity of such thruster systems. Long duration space missions are currently not possible because of risk that astronauts are greatly exposed to space radiation. Advanced nano materials such as newly developed isotopically enriched boron nanotubes could provide better radiation shielding in future spacecrafts. These come with integrated nanosensor hulls. Even on-board electronics in spacecrafts need greater protection from space radiation. As the dimensions of electronic devices are reduced, they become more radiation tolerant. For example, quantum dot electronic devices can be tens or a hundred times more radiation tolerant than conventional bulk space electronic devices.

Nanotechnology and space technology have been around in the world for over a decade and have been growing steadily and slowly. However, in recent times, the integration of these two fields boosted the space technology alarmingly. First of all, developments in the field of nano materials, nano sensors and nano instruments, have vastly reduced size, weight and increased precision and quality of launching vehicle, satellites and spacecrafts. Information Technology, especially the cloud, can improve dramatically due to nano satellites.

The commercial space industry is slowly becoming behaving like the 20^{th} century computer revolution. Just 30 years ago, access to a computer was limited and expensive. Today computers are inexpensive and are for everyone. Similarly, space technology is undergoing a potentially more dramatic transformation. Access to space today is widely expensive, and limited to governments and a few large corporations. Now nanosatellites and companies like SkyBox are transforming space access, making it less expensive and thus radically altering the society.

The Space Technology Working Group aims to support space technology development in the Asia -Pacific region by Active information exchange, Corporation seeking and providing opportunities to experts from space agencies, academic institutions and private sectors in the region. It mainly aims in developing nanosatellites for engineering management. These satellites provide more practical applications for space programs such as monitoring, reduction and removal of space debris for risk mitigation and to provide better launch environment. European Union lead QB 50 project is another ambitious project in nanosatellite line. It involves cooperative efforts by universities and research institutes in 23 nations. Asian nations involved in this project include South Korea, Taiwan and to a certain extent China. The first group of 28 QB50 nano satellites will take soundings in the largely unmeasured lower atmosphere, between 200 km and 380 km above the earth.

Recently billionaire space enthusiasts such as Elon Mask, founder of Tesla car company, have joined space race with their own rocket. Globally the space business is forecast to reach 400 billion pounds (dollar 495 billion) by 2030. Cube satellites are slowly exploding and mushrooming. Cube satellites can compete with nano – satellites. All of these are designed to gauge densities in Earth’s lower thermo sphere. The frame of nanosatellite is usually made out of Alluminium and usually machined. Instead, 3-D printed thermoplastic-based frame can also be used. This frame is coated with Nickel for conductivity, which gives it light weight and strong structure. Today nanosatellites can carry a range of scientific instruments, cameras and sensors. In 2011, China has successfully launched two scientific nano satellites. A ‘Long March II C ‘rocket carried ‘Nano satellite I’ which weighted 25 kg and ‘Experimental Satellite I’ weighing 204 kg. This successful launch has made China the fourth country in the world that is capable of launching nano – satellites after Russia, the US, and Britain.

Singapore is mainly aiming to launch microsatellites to equatorial orbits. This is mainly because it will result in a significant reduction in cost for operators seeking a global network with 24/7 coverage. One potential use of such a network is to enable a nation-wide network of sensors for autonomous vehicles. NASA has included a concept of self-healing spaceships in their 2030 nanotechnology space mission. Just as our skin heals from small wounds and injuries, the nanostructural components of these space craft's heal from damages caused by meteors that strike the spaceship. Miniaturization is proceeding at a very fast rate in space innovation. High-level miniaturization may be achieved by applying nano / micro technologies. Integration of micro/ nanoelectronics with peripherals and micromechanics will result in devices called Application Specific Integrated Micro Instruments. Nanomachines can compute really fast and make critical decisions in the future. So these can become better, faster and more reliable in space in coming years.

Conclusion:

In conclusion, nanotechnology continues to be a driving force in scientific innovation, with a wide array of applications and future possibilities. However, addressing challenges related to safety, ethics, and societal implications is essential for realizing the full potential of nanotechnology in a responsible and sustainable manner. The collaborative efforts of researchers, policymakers, and the public will play a crucial role in shaping the future trajectory of nanotechnology. Your insights and opinions on these topics would be valuable for further enriching the discourse. Nanotechnology is transforming the field of energy harvesting and storage by offering groundbreaking solutions to address the world's energy challenges. From enhancing the efficiency of solar cells and thermoelectric devices to revolutionizing energy storage systems, nanomaterials are driving innovation and unlocking new possibilities. As research and development in this field progress, the integration of nanotechnology into mainstream energy technologies is poised to accelerate the transition towards a more sustainable and resilient energy infrastructure. With nanotechnology, the power of small is poised to make a big impact on our energy future.

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NANOTECHNOLOGY ADVANCEMENTS IN NURSING: EXPLORING CUTTING-EDGE RESEARCH

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Abstract:

Nanotechnology is an inter-disciplinary branch of science and technology that focuses on the manipulation of matter on the nanoscale, usually between 1-100 nanometers. Nanotechnology blends various aspects of materials science, electrical/electronic engineering, biology, chemistry, physics and computer science to create a synergy of knowledge to improve modern science. The human race was hit hardly during the COVID-19 pandemic, which led to the loss of millions of lives across the globe and has created long-lasting socio-economic problems. Nanomaterials, based on their completely unique properties after fabrication have played a vital role in healthcare, especially combating the coronavirus. This has been achieved through advances in vaccines, drug delivery, diagnostics and personal protective equipment (PPE) for healthcare workers. Scientists must sustain the success of nanotechnology applications in COVID management.

Keywords: COVID-19 pandemic, advances in vaccines, Nano medicine, Nano biosensors.

Introduction:

Nanotechnology is an emerging interdisciplinary technology that has been booming in many areas during the recent decade, including material science, mechanics, electronics, optics, medicine, plastics, energy electronics and aerospace. The “Nano” in Nanotechnology comes from the Greek word “Nanos” that means dwarf. Scientists use this prefix to indicate 10-9 or one billionth. One nanometer is one billionth meter that is about 10000 times smaller than the diameter of a single human hair.

Definitions:

Nanotechnology

It is defined as the study of controlling, manipulating and creating systems based on their atomic or molecular specifications. It is the ability to manipulate matters at atomic, molecular and supra-molecular levels for creation of newer structures and devices. It is the science which deals with structures sized between 1: 100 nanometer (nm).

Nano science

It is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at larger scale.

Nanomaterial

It is an object which has, at least, one dimension in the nanometer scale, which is conventionally ranging from one to a few hundred nanometers.

Applications of nanotechnology in medicine and healthcare

Nanotechnology has a significant range of potential biomedical applications and is being used to develop Nano devices and structures to prevent, treat and monitor diseases. Some of the principal applications of Nano medicine are in the areas of diagnostics and testing, drug discovery, development and delivery, tissue engineering, medical instruments and devices and surgical treatments.

- Applications of nanotechnology in medicine currently being developed involve employing Nano-particles to deliver drugs, heat, light or other substances to specific cells in the human body.
- Engineering particles to be used in this way allows detection and/or treatment of diseases or injuries within the targeted cells, thereby minimizing the damage to healthy cells in the body.
- With the help of nanotechnology, damaged tissue can be reproduced or repaired. These so called artificially stimulated cells are used in tissue engineering, which might revolutionize the Nano devices can be used in stem cell research in tracking and imaging them, transplantation of organs or artificial implants.

Disease screening and diagnosis

- Nanotechnology offers a multitude of options for detecting, diagnosing, monitoring and treatment of disease.
- For example, semiconducting Nano crystals called quantum dots can enhance biological imaging for medical diagnostics.
- When illuminated with ultraviolet light, they emit a wide spectrum of bright colors that can be used to locate and identify specific kinds of cells and biological activities.
- These crystals offer optical detection up to 1000 times better than conventional dyes used in many biological tests, such as MRIs, and render significantly more information.

Disease detection

- Nanomedicine is an intriguing application for disease prevention, detection, therapy, and monitoring, from bioengineered nanoparticles that target and kill cells and biocompatible tissue implantation to nanosized implanted biosensors.
- However, while basic nanomedicine applications such as custom medicines and medical instruments have already been used in mainstream medicine for more ambitious uses, such as multipart nanomedical devices, the unique properties of nanoparticles may be capitalised on at the molecular level.
- There is a larger surface area for chemical attachment on this small scale, which facilitates the handling of molecules into fine, adjusting the behaviour of particles. Nanomaterials are also tiny enough to enter the live cells.

Detection of body oxygen

- Nanosensors can detect oxygen and carbon dioxide concentrations in the body and the presence of hazardous materials.
- Detecting malignant digestive organs and food sensitivity enables individual diet and nutritional programs to be part of their uses. The harm to healthy cells is a significant concern during treatment with frequent chemotherapy and radiation.
- New nanomedical methods are employed to treat skin cancer, allowing for adequate supply to specific tumour locations and targeting cells with lesser harmful side effects of medication and other theoretic therapies.
- A novel way of identifying cancer cells in the circulation, named NanoFlares, is being utilised with nanomedicine.
- NanoFlares are particles intended to attach to cancer cells' genetic objectives and emit light when that particular genetic objective is identified.

Nanotechnology in wound healing

In tissue regeneration, an increasing number of cutting-edge nano therapies are now being studied in a clinical trials. Several nanoscale techniques, comprising nanoparticles, were investigated for targeting distinct stages of wound healing. There are 02 types of nanomaterials exploited in the healing process:

1) nanomaterials with inherent characteristics useful in the treatment of wounds and

2) NPs are used as delivery vehicles for pharmaceutical agents.

Drug delivery

- Nano medicines used for drug delivery are made up of Nano scale particles or molecules which can improve drug bioavailability.

- For maximizing bioavailability both at specific places in the body and over a period of time, molecular targeting is done by Nano engineered devices such as Nano robots.
- The molecules are targeted and delivering of drugs is done with cell precision. In vivo imaging is another area where Nano tools and devises are being developed for in vivo imaging.
- Using Nano particle images such as in ultrasound and MRI, Nano particles are used as contrast.
- The Nano engineered materials are being developed for effectively treating illnesses and diseases such as cancer.

Medical nano robots

- The research and development of Nano robots with embedded Nano biosensors and actuators is considered a new possibility to provide new medical devices for doctors.
- The use of micro devices in surgery and medical treatments is a reality which has brought many improvements in clinical procedures in recent years.
- For example, among other biomedical instrumentation, catheterization has been successfully used as an important methodology for heart and intracranial surgery.
- More complex molecular machines, or Nano robots, having embedded nanoscopic features represent new tools for medical procedures.

Nanotechnologies for the treatment of cardiovascular diseases

- Cardiovascular diseases are another field where the properties of nanoparticles may be leveraged. Cardiovascular diseases are the leading cause of death globally, and the rates are increasing alarmingly, due to an increase in sedentary lifestyles.
- Common examples of cardiovascular diseases that affect several individuals includes stroke, hypertension and restriction or blockage of blood circulation in a specific area. These diseases are the most common causes of prolonged disability and death.
- Most cardiovascular risk factors (for example, for hypertension, smoking, hypercholesterolemia, homocystinuria and diabetes mellitus) are associated with impaired nitric oxide (NO) endothelial production. Impaired endothelial function is established to be the first step in atherosclerosis. Gold and silica nanoparticles have been developed to improve NO supply for possible application in cardiovascular diseases, where low NO bioavailability occurs.
- Systemic administration of the 17-βE loaded CREKA-peptide-modified-nanoemulsion system has been shown to reduce the levels of pathological contributors to early

atherosclerosis by reducing lesion size, lowering the levels of circulating plasma lipids and decreasing the gene expression of inflammatory markers associated with the disease.

Current applications in medicine

- Most applications of nanotechnology in medicine are still under development. Nano crystalline silver is already being used as an antimicrobial agent in the treatment of wounds. Following applications also will be released very soon:
- Dots that identify the location of cancer cells in the body.
- Nanoparticles deliver chemotherapy drugs directly to cancer cells to minimize damage to healthy cells.
- Nano shells that concentrate the heat from infrared light to destroy cancer cells with minimal damage to surrounding healthy cells.
- Nanotubes used in broken bones to provide a structure for new bone material to grow.
- Nanoparticles that can attach to cells infected with various diseases and allow a doctor to identify, in a blood sample, the particular disease.

Nanotechnology in electronics: Nano electronics

Nano electronics holds some answers for how we might increase the capabilities of electronics devices while we reduce their weight and power consumption. Some of the Nano electronics areas under development include:

- Improving display screens on electronics devices. This involves reducing power consumption while decreasing the weight and thickness of the screens.
- Increasing the density of memory chips. Researchers are developing a type of memory chip with a projected density of one terabyte of memory per square inch or greater.
- Reducing the size of transistors used in integrated circuits. One researcher believes it may be possible to "put the power of all of today's present computers in the palm of your hand".

Nanotechnology, energy and environment

Nanotechnology will play a critical role in coming 50 years by protecting the environment and providing sufficient energy for a growing world. The advanced techniques of nanotechnology can help storage of energy, its conversion into other forms, ecofriendly manufacturing of materials and by better enhanced renewable energy sources.

- Nanotechnology can be used for less expensive energy production and for renewal energies, in solar technology, nano- catalysis, fuel cells and hydrogen technology. Carbon nano tube fuel cells are used for storage of hydrogen, thus finds application in power cars.

Bio-Kil nanotechnology-based antimicrobial approach used in ICU

Bio-Kil (Cargico Group, Taiwan) is a quaternary ammonium compound (QACs) antibacterial agent composed of inorganic metal materials. Pathogens are drawn to Bio-Kil molecules due to their high binding structure and strong electric field. Their powerful electrical charge destroys the microbes' membrane proteins, killing germs. The Bio-Kil® anti-bacterial catalyst creates a direct covalent bond with the surfaces of the ICU's equipment, including workstations, nurses' stations, desktops, computer keyboards, phones, and surfaces close to patients, where it provides a long-lasting bacterial activity. Lower bacterial counts in the hospital's environment lessen the chance that equipment, surroundings, and linens will become contaminated, which lessens the risk of HAIs brought on by bacterial colonization. Bio-Kil substantially decreased the number of microorganisms in the ICU. Maintaining a secure environment and disease control strategies in healthcare settings is crucial to avoid HAI

Advantages of nanotechnology:

- Minimize energy and materials used in manufacturing.
- Cost performance advantages.
- Improve reproductively.
- Improve accuracy and reliability.
- Increase selectivity and sensitivity.

Disadvantages of nanotechnology:

- Require huge investment.
- Micro components are costly compared to macro components.
- Design includes very much complex procedure.
- Need high knowledge.

Risks of nanotechnology

- A small Nano machine capable of replication could in theory copy itself too many times. If it were capable of surviving outdoors, and using biomass as raw material, it could severely damage the environment.
- Sufficiently powerful products would either hostile governments or angry individual, to wreak havoc.
- Destructive Nano machines could do immense damage to unprotected people and objects.
- If the wrong people gained the ability to manufacture any desired product, they could rule the world, or cause massive destruction in the attempt. Certain products such as powerful aerospace weapons, and microscopic antipersonnel devices, provide special cause of concern.

Challenges for nanotechnology:

- Lack of knowledge Nano particles components and their characteristics.
- Lack of uniformity of toxicity
- Lack of standard synthesis protocol
- Lack of efficient analytical tools
- Lack of understanding of impact on biological system
- Lack of standardized safety guidelines
- Lack of well trained workforce

Role of nurse in nanotechnology (Nursing implications)

- Nanotechnology will have substantial implications for nursing informatics. These implications would involve the electronic health record design, systems interoperability and safety controls.
- Nurses are in a prime position to influence and advocate for safe and ethical use of nanotechnologies in the workplace.
- Nurses will need to create care plans to assist patients in their more independent role.
- Nurses need to be educated on occupational safety guidelines regarding safe handling of nanomaterial in the workplace.
- The nurse will need to understand the drug metabolism and pharmacokinetics of Nano medicines in order to achieve appropriate therapeutic dosing.
- Nurses in some oncology practices could potentially be responsible for recommending molecular profiling and writing molecular based treatment regimens.
- It’s important for nurses to become familiar with the concept of targeted drug therapies so that they can communicate with their patients about these new treatments so that the patients can then make informed treatment decisions.
- Incorporates theories, principles, and concepts from nanotechnology into informatics practice.
- Systematically determine the impact of an informatics solution within nursing and healthcare (Social, legal, and ethical impact).

Safety and ethical guidelines regarding safe handling of nanomaterial:

- Safety and risk management are the most importance with this new technology.
- The safe and ethical use of nano-materials is the most immediate concern.
- The key risks are related to liability, privacy, financing and the effectiveness and safety of products.
- Precautions to avoid inhalation of nanomaterial must be taken.

- Current gloves, masks and gowns may not provide sufficient protection.
- There are only a few research studies that are available regarding safety of nanoparticles and nanomaterial.
- Researchers have discovered that nanoparticles can cause inflammatory reactions and they can potentiate the effect of medications
- The behaviour of nanomaterial in humans is not well understood

Conclusion:

Nanotechnology is a rapidly progressing field of engineering and medicine that holds that key to advancing medical care in many areas. Nanomedicine was particularly instrumental in the development of vaccines, testing and therapeutics during the COVID-19 pandemic.

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REVIEW ON NANOFERTILIZERS FOR BETTER AGRICULUTURE

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Abstract:

Nanotechnology has transformed today's world tremendously. It has numerous uses in a wide range of societal fields, including engineering, agriculture, food, medicine, and polymer technology. The greatest and most promising remedy for issues with conventional fertilizer in the agricultural system is nanotechnology. The main challenge of current agriculture is to fulfil food demands efficiently. This paper will highlight the use of nanofertilizers in the field of agriculture and discuss the impact of nanofertilizers on agriculture.

Keywords: Nano fertilizer, nanotechnology, nanoparticles, nutrients, crop yield

Introduction:

Agriculture plays a vital role in economic foundation of developing countries. Key factors affecting agriculture field are water, climate, and fertilizers. Fertilizers contribute more to increase agricultural production. But use of chemical fertilizers greatly affects soil health and its efficiency. Due to the growth of high-yielding crop types, greater cropping intensity, and decreasing use of organic manures, macro and micronutrient deficiencies in crops and soil have increased intensely over the past several years worldwide [1]. Application of nanomaterials in agriculture is to reduce the amount of spread chemicals, minimize nutrient losses in fertilization and increased yield through pest and nutrient management. Numerous possible advantages include improving the safety and quality of food, lowering the number of inputs used in agriculture, improving soil absorption of nanoscale nutrients, etc. [2]. Due to numerous advantages of nano-fertilizers gained attention of the soil scientists and environmentalists.

Nanoparticle

A nanoparticle is a small particle with at least one dimension less than 100 nm. 1 nanometer $= 10^{-9}$m = 1 billionth of a meter. Nano sized particles can even penetrate through the cell wall in plants and animals. This process is used by nanotechnologists to deliver at the cellular level, which is more efficient than using the traditional approach. Nano particles are regarded as atoms or molecules and eventually relate to bulk material, which causes substantial changes in the material's physicochemical characteristics.

Nanofertilizer

Fertilizers are used to improve plant growth and output. These fertilizers are artificially synthesized inorganic chemical compounds. A material known as nano-fertilizer has the capacity to store a large quantity of nutrients for gradual and consistent release. When compared to conventional fertilizers, nano fertilizers can have higher use efficiencies and are expected to be needed in significantly smaller quantities. Three primary categories of Nano-fertilizer are suggested [3].

1. **Nanoscale fertilizer:** These are nanoparticles used as inputs containing nutrients. This increases absorption and overall effectiveness while providing a potentially nutritious amount in a less harmful way. This group includes fertilizer nano-objects made of urea, ammonium salts, peat, and other conventional fertilizers.
2. **Nanoscale additives:** These are traditional fertilizers with nanoscale additives. In this case, a nanomaterial replaces a little portion of macroscale inputs as an additive to enhance the macroscale inputs' qualities rather than acting as the nutrient itself. It may act some role in the plant growth, or it may be a supplement substance that can provide a binder or water holding material. Nanoscale additives give plants anti-microbial or insect resistance.
3. **Nanoscale coating:** These are traditional fertilizers coated or laden with nanoparticles. In this type the macroscale fertilizer is encapsulated by the nanoscale coating or a film. There could be nanoscale pores in the coating which can facilitate the slow release of nutrients solubility. The encapsulation of advantageous microorganisms, which can effectively enhance plant root growth and serve health objectives, is another fantastic application of this type. Some clays, such as kaolinites, smectites, halloysites, and palygorskites, are used in fertilizer products.

Nanoscale fertilizer inputs

A nano fertilizer is a product that carries nutrients to crops in one of three ways. The nutrient can be supplied as nanoparticles or nano-emulsions, contained inside nanomaterials like nanotubes, or coated with a thin layer of protective polymer film on the surface. Nanoscale fertilizer inputs are discussed here [3,4,5].

1. Nitrogen-based nanoparticles:

Nitrogen is the most important nutrient available for plant growth. Nitrogen utilization efficiency (NUE) can be enhanced by nitrogen based nano fertilizers as traditional fertilizers have less NUE. Urea is used to get ample amount of nitrogen. Slow release of nitrogen to the plant is needed. These fertilizers improve crop productivity. Urea-Hydroxyapatite Nanohybrids fertilizer, Urea coated nanohydroxyapatite composite, urea-silica nanohybrids, N bio-fertilizer and Khazraa K chelate Nano-fertilizer, Urea–hydroxyapatite nanohybrid, Urea coated nano calcium carbonate (Urea-CC) nanocomposite, are some of the nitrogen based nano fertilizers.

2. Phosphorus nano fertilizers:

The second major nutrient for the plant is phosphorus (P). Certain commercially available water-soluble phosphate salts, as triple superphosphate, diammonium phosphate, mono ammonium phosphate, (NH3, or Ca $(H_2PO_4)_2$), are used as fertilizers. Phosphorus-based nano fertilizer would enhance agronomical production, use efficiency of P, and improve the surface-water quality. Synthesized HA nanoparticles (A), and urea surface-modified HA nanoparticles (B) are also used. By adding nitrogen (N), phosphorous (P), and potassium (K) to chitosan nanoparticles, the NPK nano fertilizer is formed.

3. Nano silica:

Additionally, silica material is used to distinguish between components that are important to a plant's existence and those that are not. While most plants do not require silica to survive, plants that are exposed to various environmental stressors can adapt and benefit from its presence. Nanomaterials like nano-SiO_2 or nano-ZnO are used.

4. Titanium nanoparticles:

Materials that are photocatalytic are becoming more and more recognized as valuable resources for agriculture. TiO_2-PN has been applied as a growth-regulating, antibacterial, and fertilizer-like substance. Light absorption and photoenergy transfer were both enhanced by titanium nanoparticles. TiO_2 nanoparticles can promote the plant growth.

5. Zinc oxide nanoparticles:

In areas where there is a zinc shortage, the most common zinc fertilizer given to crops is zinc oxide. ZnO nano fertilizers can proceed novel solubility option of Zinc oxide nanoparticles to improve the efficiency of Zn fertilizers.

6. Copper oxide nanoparticles:

While beneficial for germination, copper oxide nanoparticles are phytotoxic during seedling growth. A visual representation of the many advantages of metal nanoparticles demonstrates the potential contribution of copper nanoparticles to improved plant growth and yield.

7. Iron nano-fertilizers:

Iron is an essential element for metabolic functions in the plant. It influences yield of the crop. These fertilizers are the ideal alternative sources, especially in iron-deficient soils. These fertilizers improve seed germination and promote the crop growth parameters, promote many growth parameters, chlorophyll, and protein levels.

8. Manganese nano-fertilizers:

Manganese is involved in ATP (Adenosine triphosphate) and protein and fatty acids biosynthesis, photosynthesis, and metabolism of nitrogen. Application of these fertilizers give a high rate of nitrogen assimilation and metabolism comparing with conventional Manganese fertilizer. Various researchers revealed that in some plants growth, productivity, efficiencies of photosynthesis is enhanced by these fertilizers.

9. Boron nano-fertilizers:

It has important role in pollen grains and tubes elongation, formation of cellular walls, photosynthetic products transfer from leaves to active sites, and increases in flowers and fruits yields.

10. Zeolite-based nano-fertilizers:

It is used as a slow-release fertilizer in farming. It normally helps in slow release of the fertilizer to the plant, this way of doing makes the plant to grab entire amount of nutrients from the applied fertilizer rather than the minimal uptake.

11. Potassium nano- fertilizers:

This fertilizer enhances all physiochemical functions of plants. It is very important in opening the stomata of the plant, Photosynthesis, translocation of photosynthates, protein synthesis, ionic balance, water relationships, and the activation of more than 60 enzymes. These fertilizers are very important for seed yield and oil content in peanuts.

12. Carbon nanotubes:

Single-walled carbon nanotubes, multi-walled carbon nanotubes, PBMC nano fertilizer are used in agriculture. Study reveals that use of carbon nanotubes enhances plant growth, provide higher moisture uptake, seed growth, induce changes in metabolic function, increase in biomass, and yield of plants, increases the electron transfer rate of light-adapted chloroplasts.

Advantages of nanofertilizers over conventional fertilizers

Nano fertilizers are very crucial for eco-friendly and sustainable crop development. Some of the advantages are as follows [6, 7].

1. Provides effective nutrient absorption and utilization.
2. Lowers the danger of environmental pollution by reducing nutrient losses.
3. They have a greater diffusion than traditional synthetic fertilizers.
4. Offers controlled and slow distribution of nutrients to crop plants.
5. Helps plants to absorb nanoparticles through root exudates, molecular transporters, and nanosized porous materials. They absorb more nutrients from nanoparticles through a variety of ion channels.
6. Smaller volumes of them can do because of modest nutrient losses.

7. Shield the soil and water from early exposure, minimizing nutrient loss.
8. Increases soil fertility and provides favorable environment to microorganism growth.

Conclusion:

This review article focusses on advantages of nano fertilizers over traditional fertilizers. It showed use of nano fertilizers in agriculture is beneficial regarding plant growth, effective nutrient absorption, and utilization, reduction in nutrient loss and survival of plants in environmental stresses. Benefits of categories of nano-fertilizers with inputs are discussed here. The agriculture sector will indeed see tremendous change for the better future of agriculture.

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EXPLORING NANOTECHNOLOGY FOR ADVANCED WOUND MANAGEMENT

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Abstract:

Wound healing is a vital biological process essential for maintaining overall health, encompassing intricate mechanisms aimed at repairing damaged tissue. However, challenges such as microbial colonization and delayed healing persist, particularly in chronic wounds. Traditional wound dressings have limitations in addressing these challenges effectively, leading to a growing interest in nanotechnology for wound healing applications. Nanomaterials, particularly metal and metal oxide nanoparticles, exhibit remarkable antimicrobial properties and have demonstrated the ability to promote wound healing. Silver nanoparticles, gold nanoparticles, and zinc oxide nanoparticles, among others, have shown promise in managing wound infections and enhancing tissue regeneration. Despite their potential, the use of nanomaterials in wound healing presents safety concerns, including skin irritation and potential long-term effects on biological systems. Furthermore, the complex interactions between nanomaterials and biological tissues raise questions about their biocompatibility and toxicity, necessitating further research and regulatory oversight. Nevertheless, nanomaterials hold tremendous promise for revolutionizing wound care by offering innovative solutions to enhance the healing process and improve patient outcomes. Continued research efforts are essential to address existing limitations and unlock the full potential of nanotechnology in wound healing.

Keywords: Wounds, Nanomaterials, Proliferation Phase, Silver Nanoparticles, Wound Healing

Introduction:

Wound healing is a complex biological process that involves a sequence of events aimed at repairing damaged tissue and restoring its structure and function. From minor cuts and scrapes to more severe injuries like burns or surgical incisions, the body's ability to heal wounds is crucial for maintaining overall health and well-being. The establishment of colonies of pathogenic microorganisms at the site of skin injury throughout the process of natural healing is a typical complication with complete wound healing [1]. The bacteria in the skin microbiome at a wound site aid to avoid pathogen colonisation. Excessive biofilm production from harmful bacteria can slow recovery. Staphylococcus aureus is the most common infection discovered in wounds, whereas *Pseudomonas aeruginosa* and *Escherichia coli* impact deeper layers of skin in chronic wounds [2]. Traditionally, gauze and bandages were used for the healing of skin abnormalities. The design of the dressing must resemble the extracellular matrix (ECM) in a moist environment, have antimicrobial qualities, and promote cell proliferation and angiogenesis. This necessitates the use of specific elements with distinct capabilities. The high market demand for these resources has led to an increase in nanomaterial dressings. Pathogen-associated bare skin infections can cause significant inflammation and delayed wound healing [3]. To prevent bacterial infections and enhance natural wound healing, an antimicrobial-associated dressing for the wound is required. The growth of antimicrobial-resistant bacteria inhibits healing, emphasising the importance of not hazardous or resistant wound-dressing treatments to improve healing efficacy. In recent years, advancements in nanotechnology have revolutionized our understanding of wound healing mechanisms and introduced innovative approaches to accelerate and enhance the healing process.

Types of wounds

Wounds are categorised as acute or chronic, based on their duration and healing mechanisms [4]. Acute wounds caused by corrosive chemicals, radiation, mechanical harm, heat, or electrical shock typically heal quickly with adequate treatment. Chronic wounds are linked to certain disorders, such as diabetes mellitus, and do not follow the typical wound-healing process. Chronic wounds can be inflammatory for a long period, depending on factors including bacterial load, necrotic tissue, and moisture balance at the site. Recurrence of chronic wounds is riskier unless its root cause is treated [5]. In fact, persistent wounds can never heal or may take years to heal. Removing inhibiting variables is crucial for resolving the stage.

Wounds are divided into three forms based on their depth: superficial (loss of epidermis), partial-thickness (damaged epidermis and deeper dermal layers), and full-thickness (ruptured subcutaneous fat and deeper tissue) [6].

Physiology of wound healing

Wound healing is a complex physiological process involving a series of coordinated events aimed at restoring the integrity of damaged tissue. There are generally four overlapping stages in wound healing:

Hemostasis phase: This is the initial response to injury aimed at stopping bleeding. Blood vessels constrict to reduce blood flow, and platelets aggregate at the site of injury to form a temporary plug. This is followed by the activation of the coagulation cascade, leading to the formation of a fibrin clot that helps to stabilize the wound and prevent further blood loss [7,8].

Inflammation phase: The inflammation appears immediately following the injury and often lasts up to three days. Platelet degranulation during early hemostasis activates a complement cascade that releases histamine, serotonin, proteases, and other cellular mediators from basophils and mast cells. It produces vasodilation, increased vascular permeability and blood flow, resulting in irritation and heat. Inflammation begins shortly after injury and serves to remove debris, pathogens, and damaged tissue from the wound site [9]. Immune cells, particularly neutrophils and macrophages, migrate to the site of injury to phagocytose pathogens and cellular debris. Inflammatory mediators such as cytokines and growth factors are released, which stimulate the proliferation of fibroblasts and endothelial cells and initiate the next stages of wound healing [10].

Proliferation phase: During the proliferation phase of wound healing, several key processes contribute to tissue repair and regeneration. Fibroblasts, specialized cells responsible for collagen production, migrate into the wound bed and deposit new collagen fibers. Collagen, the main structural protein in connective tissue, provides strength to the healing wound, restoring its structural integrity [11]. Concurrently, angiogenesis occurs as endothelial cells proliferate and form new blood vessels within the wound site, supplying oxygen and nutrients crucial for tissue repair. This increased blood flow supports the metabolic needs of cells involved in healing and facilitates the removal of waste products. Epithelial cells at the wound edges proliferate and migrate across the wound bed, promoting wound closure and restoring the protective barrier function of the skin. Additionally, granulation tissue forms during this phase, consisting of new blood vessels, fibroblasts, and inflammatory cells. This tissue fills the wound bed, providing a scaffold for tissue regeneration [12]. Wound contraction also takes place, facilitated by myofibroblasts with contractile properties. These cells pull the wound edges together, reducing the wound's size and minimizing the area requiring tissue regeneration.

Remodeling phase: Maturation and remodelling represent the final step of wound healing. This phase typically begins three weeks after wound creation and can last up to a year or longer, depending on the kind of wound. It involves normal epithelium expansion and wound scar tissue maturation. This phase is just the equilibrium between production, deposition, and breakdown. Wound remodelling involves myofibroblasts, endothelial cells, and macrophages [13]. Fibroblasts crosslink collagen, forming organised grids that increase tissue tensile strength and account for approximately 80% of unwounded skin. Excess collagen is broken down and removed by matrix metalloproteinases (MMPs), and the wound undergoes contraction, reducing its size. The final scar tissue may not have the same strength or elasticity as the original tissue but still provides adequate structural support [14].

Nanomaterials in wound healing

Nanotechnology has revolutionized various fields, including wound healing, by offering innovative solutions to enhance the healing process and improve outcomes. Nanomaterials, which are materials with dimensions on the nanometer scale, have shown great promise in wound care due to their unique properties such as high surface area-to-volume ratio, tunable physicochemical characteristics, and ability to interact with biological systems at the molecular level [15]. There are two types of nanomaterials utilised in wound therapy: those having intrinsic features that facilitate wound treatment and those that serve as therapeutic agent delivery vehicles.

Intrinsic antibacterial agents in wound healing

Metal and metal oxide nanomaterials

Metal and metal oxide nanoparticles offer superior wound-healing therapy compared to conventional components. They also have comparable wound-healing and antimicrobial properties due to their inherent nature. The dimension, design, surface alteration, zeta potential, permeability, and hydrolysis behaviour of metallic nanoparticles influence their possibilities for use in biological applications [16,17]. The most explored metallic nanoparticles are silver (Ag), gold (Au), and zinc oxide (ZnO), due to their favourable physiochemical characteristics and antibacterial activity.

Silver nanoparticles (AgNPs)

They possess powerful antimicrobial properties that effectively target various pathogens, including bacteria, fungi, and viruses, by disrupting their cell membranes, inhibiting enzymatic activity, and inducing oxidative stress, ultimately resulting in microbial death. Utilizing these properties, AgNPs have been integrated into wound dressings, hydrogels, and creams, offering a promising solution for preventing and treating wound infections, especially in cases of chronic wounds where traditional antibiotics might fail due to antibiotic resistance. Moreover, research indicates that silver nanoparticles play a beneficial role in wound healing processes. They have been found to reduce inflammation, stimulate the formation of new blood vessels (angiogenesis), and enhance the deposition of collagen, all of which contribute to faster wound closure and tissue regeneration [18,19].

Gold nanoparticles (Au NPs)

They have procured attention for their potential role in wound healing due to their unique properties and biocompatibility. These nanoparticles have demonstrated antimicrobial activity against various pathogens, including drug-resistant bacteria, by disrupting bacterial cell membranes and altering membrane potentials, ultimately leading to bacterial death. Additionally, AuNPs possess anti-inflammatory, which can help reduce inflammation at the wound site and promote tissue regeneration [20]. In wound healing, AuNPs can be integrated into various wound dressings or hydrogels to enhance their effectiveness. When combined with natural polymers like collagen or chitosan, AuNPs improve wound closure rates by promoting cell proliferation and migration, stimulating angiogenesis, and enhancing collagen deposition. Moreover, AuNPs can be functionalized to deliver therapeutic agents, such as growth factors or antibiotics, directly to the wound site, thereby accelerating the healing process [21]. Research indicates that AuNP-based wound dressings exhibit superior antibacterial activity, reduced inflammation, and enhanced tissue regeneration compared to traditional wound dressings. Furthermore, these nanomaterials offer the advantage of being highly biocompatible and non-toxic, making them suitable for clinical applications.

Zinc oxide nanoparticles (ZnO NPs)

Zinc oxide nanoparticles demonstrate antimicrobial efficacy against a diverse range of pathogens, encompassing bacteria, fungi, and viruses, rendering them an effective tool for managing wound infections [22]. Additionally, ZnO NPs showcase anti-inflammatory characteristics and have the ability to advance wound healing through the modulation of inflammatory reactions, hastening tissue regeneration, and amplifying epithelialization. They are frequently integrated into wound care products such as dressings, ointments, and creams to deliver antimicrobial protection and support the process of wound repair. When combined with chitosan hydrogel, ZnO NPs exhibit optimal antibacterial performance alongside low toxicity, rendering the composite material highly suitable for wound dressing purposes. Notably, research by Balaure et al. underscores the accelerated wound closure facilitated by a wound dressing incorporating collagen, ZnO NPs, and 1% orange essential oil, showcasing remarkable biocompatibility both in vitro and in vivo while effectively inhibiting bacterial growth [23]. Similarly, Gao et al.'s study corroborates the wound-healing capability of ZnO NPs, exhibiting them as an antimicrobial tissue adhesive through an in vivo examination utilizing a skin wound mouse model [24]. Nevertheless, the inherent toxicity associated with ZnO NPs presents a notable drawback, necessitating further exploration before their widespread application in wound healing can be fully realized. Concurrently, considerable research endeavors are underway to explore the wound-healing potential of other metals and metal oxides, including copper, titanium, magnesium oxide (MgO), iron oxide (Fe_2O_3), aluminum oxide (Al_2O_3), and copper oxide (CuO) within wound-care materials.

Non-metallic nanomaterials

Polymeric nanoparticles

They have garnered significant attention in wound healing research, comprised of biodegradable polymers like poly(lactic-co-glycolic acid) (PLGA), chitosan, or polyethylene glycol (PEG) [25]. These nanoparticles offer a versatile platform for encapsulating bioactive molecules such as growth factors, antimicrobial agents, or anti-inflammatory drugs, facilitating controlled release directly at the wound site to regulate the healing process effectively. Moreover, polymeric nanoparticles can act as carriers for cells or stem cells, facilitating their transportation to the wound area and thereby augmenting tissue regeneration and repair mechanisms. Recent research indicates that cross-linked polymer chains expand in aqueous environments, highlighting their pivotal role in wound healing. Gelatin, a natural polymer from collagen, is widely used in biodegradable wound dressings [26]. Studies show that porosity and fiber spacing in gelatin scaffolds influence skin repair, with enhanced outcomes observed in rat models. Fibrin, another natural polymer derived from fibrinogen, exhibits anti-inflammatory and cell adhesion properties, commonly used in tissue engineering. Hydrogels prevent tissue dehydration and are suitable for wound dressings, while scaffolds offer mechanical support and targeted growth factor delivery for tissue regeneration [27].

Liposomes

Liposomes play a significant role in wound healing by serving as carriers for therapeutic agents, including antibiotics and growth factors. These lipid-based nanoparticles have a hydrophobic exterior and a hydrophilic interior, allowing them to encapsulate both hydrophobic and hydrophilic substances effectively. In wound healing, liposomes can be loaded with various bioactive molecules to facilitate controlled release directly at the wound site, promoting tissue regeneration and repair mechanisms. By delivering therapeutic agents continuously and effectively to the affected area, liposomes help inhibit bacterial growth, reduce inflammation, and enhance the healing process. Their biocompatibility and ability to be tailored and integrated into wound dressings make liposomes valuable tools in modern wound care [28]. By modifying the composition of liposomes, their uptake and absorption through the bacterial cellular membrane can be enhanced. Numerous studies have explored liposomes loaded with antibiotics to combat bacterial infections, with various surface modifications being investigated [29]. Due to their negative charge, liposomes exhibit greater affinity for bacterial cell membranes, which typically carry a positive charge, compared to membranes with negative or neutral charges. For example, cationic liposomes loaded with vancomycin have demonstrated effectiveness against *methicillin-resistant Staphylococcus aureus* (MRSA) and *Staphylococcus epidermidis* (S. epidermidis) [30].

Lipid nanoparticles

Lipid nanoparticles play a significant role in wound healing by serving as effective carriers for various medicinal agents, including drugs, growth factors, and small interfering RNA (siRNA). These nanoparticles, comprised of hydrophobic exteriors and hydrophilic interiors, offer several advantages that make them valuable tools in wound therapy. One crucial aspect of lipid nanoparticles in wound healing is their capacity to encapsulate both hydrophobic and hydrophilic therapeutic agents. This ability enables them to protect medicinal agents from degradation and ensure sustained drug release, which is essential for regulating the healing process effectively [31]. By encapsulating bioactive molecules such as growth factors or antimicrobial agents, lipid nanoparticles facilitate controlled release directly at the wound site, promoting tissue regeneration and repair mechanisms. Solid lipid nanoparticles (SLNs) and nanosized lipid carriers (NLCs) are two types of lipid nanoparticles that have been developed as effective delivery systems for wound therapy. These carriers encapsulate biocompatible components, ensuring sustained drug release and promoting close interaction between drugs and bacterial cells. For example, SLNs loaded with antimicrobial peptides or antibiotics have demonstrated potent bactericidal effects against various pathogens, ultimately promoting wound healing. Furthermore, lipid nanoparticles offer advantages over traditional delivery methods due to their smaller size, which facilitates diffusion into biofilms and enhances the delivery of therapeutic agents to the affected area. By modifying the composition of lipid nanoparticles, their uptake and absorption through bacterial cell membranes can be enhanced, leading to increased intracellular drug concentration and improved efficacy against bacterial infections [32,33].

Limitation of nanomaterials in wound healing

Nanoparticles (NPs) exhibit promising potential for enhancing wound healing, yet their use necessitates rigorous assessment of biological safety due to direct contact with wound tissue. Notably, the skin barrier is compromised in wounds, making it imperative to ensure the safety of NPs prior to application. Skin irritation and allergies are frequently reported adverse effects associated with NP exposure, particularly with carbon nanotubes and nickel NPs due to ion release and surface coatings. Research indicates that NP exposure can exacerbate skin inflammation, irritation, and conditions like psoriasis. Enhancing NP stability can mitigate dermatitis, achieved through the use of stabilizers such as metal shells, polymers, or surfactants, and employing low sensitization materials for NP surface coating. Concerns also arise regarding potential DNA damage and reduced gene methylation with NP exposure, suggesting a potential risk of cell cancer, although clear evidence is lacking. Extended exposure studies are crucial to elucidate the effects of prolonged NP exposure on skin cells and systemic effects post-NP entry into the bloodstream. To address complications like hemolysis caused by certain metal NPs, adjustments to the material's physicochemical properties or coating NPs with biologically active substances like polysaccharides and phospholipids may be beneficial. Furthermore, concerns regarding NP distribution throughout the body, potential organ damage, tumor formation, and adverse effects during pregnancy underscore the need for comprehensive toxicity evaluations in wound healing. While existing studies primarily focus on acute adverse reactions, broader investigations encompassing various types of NPs are warranted to address these concerns effectively.

Conclusion:

In conclusion, wound healing is a complex biological process vital for maintaining overall health and well-being. Despite advancements in wound care, challenges such as microbial colonization and delayed healing persist. Traditional wound dressings have limitations in addressing these challenges effectively, leading to a growing interest in nanotechnology for wound healing applications. Nanomaterials, particularly metal and metal oxide nanoparticles, have demonstrated remarkable antimicrobial properties and the ability to promote wound healing. Silver nanoparticles, for instance, exhibit potent antimicrobial activity against a wide range of pathogens and have been integrated into wound dressings to prevent infections and accelerate healing. Similarly, zinc oxide nanoparticles possess antimicrobial and anti-inflammatory properties, making them effective in managing wound infections and enhancing tissue regeneration. However, the use of nanomaterials in wound healing is not without limitations. Safety concerns, such as skin irritation and allergic reactions, as well as potential long-term effects on biological systems, must be thoroughly evaluated. Additionally, the complex interactions between nanomaterials and biological tissues raise questions about their biocompatibility and potential toxicity, necessitating further research and regulatory oversight. Despite these challenges, nanomaterials hold tremendous promise for revolutionizing wound care by offering innovative solutions to enhance the healing process and improve patient outcomes. Continued research and development efforts are essential to address existing limitations and unlock the full potential of nanotechnology in wound healing.

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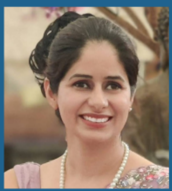

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