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ROLE OF PHARMACEUTICAL NANOTECHNOLOGY IN DEVELOPMENT: RECENT ADVANCE AND FUTURE DIRECTION

Vaishnavi G. Baviskar*, Yashkumar K. Bhadane and Dr. Amol D. Landge

Shram Sadhana Bombay Trust's Institute of Pharmacy Bambhori, Jalgaon.

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***Corresponding Author**
Vaishnavi G. Baviskar
Shram Sadhana Bombay Trust's Institute of Pharmacy Bambhori, Jalgaon.

ABSTRACT
Pharmaceutical Nanotechnology Has Revolutionized Drug Delivery and Treatment Outcomes In Recent Years. Nanoparticle Based Systems Offer Improved Solubility, Bioavailability, and Targeted Therapy. Liposomes, Polymeric Nanoparticles, and Metallic Nanoparticles are Widely Used for Drug Delivery. Nanocarriers, Such as Antibody-conjugated Nanoparticles and Ligand Targeted Nanoparticles, Enable Targeted Therapy. Nano Formulations, Including Nanosuspension, Nano Emulsions and Nanocrystals, Improve Solubility and Bioavailability. Application in Cancer, Infectious Diseases and Cardiovascular Diseases Have Shown Promising Results. However, Challenges Persist, Including Scalability, Toxicity and Regulatory Framework. Future Directions Include Personalized Nanomedicine, Nano Immunotherapy and Nanorobotics.

KEYWORDS: Pharmaceutical Nanotechnology, Bioavailability, Drug Delivery, Nanomaterials Future Direction.

1. INTRODUCTION

In Pharmaceutical Nanotechnology, Nanoparticles are Used To Improve Drug Delivery, Targeting and Release. This Can Lead To Enhanced Efficacy, Reduced Toxicity and Improved Patient Outcomes. Nanotechnology Has Revolutionized Various Industries and Pharmaceuticals been No Exception.[1,2]

2. RECENT ADVANCES IN NANOTECHNOLOGY

2.1] Liposomes

Nanoparticles Made of Lipids That Can Encapsulate Drug and Target Specific Cells or Tissues. Liposomes are Spherical Vesicles Composed of Phospholipid Bilayers. Liposomes Consist of Aqueous Core Surrounded by a Phospholipid Bilayer, Allowing for Drug Encapsulation.[3,4,5,6]

2.2] Polymeric Nanoparticles

Polymer Nanoparticles can be Tailored to Have Specific Sizes, Shapes and Surface Properties, Making Them Useful For a Wide Range of Applications, Including Drug Delivery, Imaging and Diagnostics. The Size of Polymer Nanoparticles can Range From 10 – 10000 nm, with Smaller Particles Being More Suitable for Drug Delivery.[7]

2.3] Metallic Nanoparticles

The Metallic Nanoparticles Made of Metals Like Gold or Silver That Can Absorb Near Infrared Light and Generate Heat To Kill Cancer Cells.[8,9] Metallic Nanoparticles Can be Synthesized Using Various Methods, Including Chemical Reduction, Physical Vapor Deposition and Biological Method. The Size and Shape of Metallic Nanoparticles Can be Controlled by Adjusting The Synthesis Conditions. The Optical Properties of Metallic Nanoparticles Can be Tuned by Adjusting Their Size and Shape.[10]

2.4] Nanosuspensions

They Have shown Potential For Improving drug Delivery and Bioavailability. The Nanosuspension Improved solubility of Poorly Soluble Drugs. They Have High Surface Area due to Small Particle Size. The Particle Size Ranges From 10-1000 nm.[11]

2.5] Nano emulsions

It is also Known as submicron Emulsions or Mini emulsions. Typically Consist of a Mixture of Oil, Water and Surfactants. They Have a Small Droplet Size, typically in the Range of 10-100 nm.[12]

2.6] Nanocrystals

Also Known as Nanocrystalline Materials or Nano powders Consist of Crystalline Particles with Diameters in the Range of 1-100 nm. The Nanocrystals have a Large Surface Area and High Reactivity Due to Their Small Size.[13]

3. FUTURE DIRECTIONS OF PHARMACEUTICAL NANOTECHNOLOGY

3.1] Nanoparticle Based Drug Delivery Systems

Use Nanoparticles as Carriers for Drugs. It is Made from Various Materials Such as Lipid, Polymers or Metals. Drug Can be Loaded into nanoparticles Through Various Methods, Such as Encapsulation or Conjugation.

Nanoparticles Can be Designed to Target Specific Sites in the Body, Such as Cancer Cells or Inflamed Tissues.[14] Example of a Specific Nanoparticle Based Formulation of the Anticancer Drug Doxorubicin, Which Uses Liposomes as the Carrier.[15]

3.2] Targeted Drug Delivery Using Nanoparticles

The Nanoparticle Uses to Deliver Drugs Directly to Specific Sites in the Body. Nanoparticles are Engineered to Have Targeting Ligands on Their Surface, Which Bind to Specific Cells or Tissues. Drugs are Released From the Nanoparticles, Allowing for Localized Drug Delivery.[16]

3.3] Personalized Nanomedicines

The Most Used Targeting Moieties Have Been Monoclonal Antibodies Since They Target Specific Molecules Expressed By a Single Type of Cells. Although Current Nano therapies are First Generation Therapies Without Active Targeting to the Desired Organ, Such as Doxil, Which is Expected to Reach Tumours. It is also significant to Keep in Mind That to implement The tailored of a Therapy, The Use of Genetic Material as the pharmacological active compound is Recommended as Compared with Pharmacological Therapies With Drugs.[17,18,19]

3.4] Scalability and Manufacturing

Scalability and Manufacturing are Crucial Aspects of Pharmaceutical Nanotechnology, Ensuring the Production of High-Quality Nanoparticles on a large Scale While Maintaining Their Uniformity, Stability and Efficacy. The Future Direction of Scalability and Manufacturing in Nanotechnology is Focused on:

i) Large Scale Production

Developing Methods for Mass Production of Nanoparticles while Maintaining Uniformity and Quality.

ii) Continuous Processing: Shifting From Batch Processing to Continuous Flow Processes for More Efficient and Cost-Effective Production.

iii) Process Analytical technology: Implementing Sensors and Analytical to Monitor and Control Production Processes in Real Time.

iv) Scalable Equipment Design: Designing Equipment That can be Easily Scaled Up or Down Depending on Production Needs.[20,21]

3.5] Nanorobotics

The Future Direction of Nano Robotics Includes

i) Biodegradable Nanorobots

Creating Nanorobots that can Degrade Naturally in the Body, Reducing Potential Toxicity and Environmental Impact.

ii) Swarm Robotics: Developing Large Number of Nano Robots That can Work Together to Achieve Complex Tasks, Such as Tissue Repair.

iii) Targeted Drug Delivery: Using Nano Robots to Deliver Drugs Directly to Specific Cells or Tissues, Improving Efficacy and Reducing Side Effects.

iv) Neurological Application: Designing Nano Robots That Can Interact With the Nervous System, Potentially Treating Neurological Disorder.[22,23,24,25]

These Future Directions Will Help to Advance The Field of Pharmaceutical Nanotechnology and Improve Drug Delivery and Therapy Outcomes.

4. APPLICATION OF NANOTECHNOLIGY IN PHARMACY

4.1] Inhibition of Vascular Remodelling

The Neointimal Hyperplasia Refers to the Proliferation and Migration of Vascular Smooth Muscle Cells in the Tunica Intima, Resulting in Arterial Lumen. Nanoparticles Can Be Used To Deliver Frugs, Such as Sirolimus or Paclitaxel, Directly to the Site of Angioplasty, Reducing Neointimal Hyperplasia.[26,27]

4.2] Gene Therapy

a) Nanoparticle Mediated Gene Delivery: Nanoparticles Can Be Engineered to Carry Genetic Material, Protecting it From Degradation and Targeting Specific Cells.

b) RNA Interface Therapy: Nanoparticles Can Deliver RNAi Therapeutics to Silence Disease Causing Genes.

c) Targeted Gene Therapy: Nanoparticles Can Be Designed To Target Specific Cells or Tissues, Reducing Off Target Effects.[28,29,30]

4.3] Lead Compound Identification

The Pharmaceutical Nanotechnology Can Improve The Delivery Process By Miniaturizing, Automation and Assay Reliability. Single Wall Nanotubes are Used Effectively in the Detection of Pathogen Surface Protein. Quantum Dots Individual Glycine Receptors For Duration Ranging From Milliseconds to Minutes to Study Their Dynamics in the Neuronal Membrane of Living Cells. The Pharmaceutical Nanotechnology is Used to Identify Pathogens in Humans, To Isolate and Purify Molecules and Cells and to Detoxify Chemicals.[31]

5. DESIGN CONSIDERATION IN PHARMACEUTICAL NANOTECHNOLGY

5.1] Particle Size & Distribution

Particle Diameter and Distribution are Critical Parameters in Pharmaceutical Nanotechnology, Affecting the Behaviour, Interactions, and Efficacy of Nanoparticles.

i) Particle Size: Nanoparticles Typically Range From 1-1000 nm In Size. Optimal Size Range for Drug Delivery

is 100-200 nm. Smaller Particles (≤100 nm) May Exhibit Increased Toxicity and Clearance. Larger Particles (≥500 nm) May Exhibit Reduced Cellular Uptake and Targeting.

ii) Particle Distribution: Monodisperse Distributions (narrow size range) are Preferred for Consistent Behaviour and Targeting. Polydisperse Distributions (broad size range) May Lead to Variable Efficacy and Toxicity.

iii) Measurement Technique: Dynamic Light Scattering (DLS) for Size and Distribution Analysis. Transmission Electron Microscopy (TEM) for measurement and structure examination. Scanning Electron Microscopy (SEM) For Size and Surface Analysis.

5.2] Drug Encapsulation and Liberation
i) Entrapment Efficiency: Maximizing Drug Loading While Minimizing Nanoparticle Size.

ii) Drug Solubility and Molecular Weight: They are Affecting the Drug Loading Capacity and Release Kinetics.

5.3] Drug Release
i) Release Kinetics: Controlling Drug Release Rate to Achieve Desired Therapeutic Effects.

ii) Sustained Release: Maintaining Therapeutic Drug Levels Over Extended Periods.

iii) Modulated Release: Releasing Drugs at Specific Sites or In Response to Environmental Stimuli.[32,33,34,35,36]

5.4] Targeting and Delivery
Targeting: Targeting Ligands can be attached to Nanoparticles to Enhance Specificity and Uptake. Nanoparticle Surface Properties can be Modified to Improve Targeting and Delivery.

i) Active Targeting: Nanoparticles are Designed to Target Specific Cells or Tissues Using Ligands or Antibodies.

ii) Passive Targeting: Nanoparticles Accumulate In Target Tissues Due to Size, Charge or Hydrophobicity.

5.5] Delivery
Nanoparticles can be Designed to Deliver Drugs Across Biological Barriers, Such as the Blood-brain barrier. Controlled Release Mechanisms can be Incorporated Into Nanoparticles to Achieve Sustained Drug Delivery.

i) Controlled Release: Nanoparticles Release Drugs in a Controlled Manner, Improving Efficacy and Reducing Side Effects.

ii) Site-specific Delivery: Nanoparticles Deliver Drugs Directly to the Target Site, Increasing Bioavailability and Reducing Systemic Toxicity.[37,38]

5.6] Material Evaluation Parameter
i) Biologic Acceptability: The Material Should Be Non-toxic and Non-immunogenic.

ii) Biodegradability: Material Should Be Degrade Into Non-toxic Byproducts.

iii) Targeting: Materials Can Be Functionalized For Active Targeting.

iv) Controlled Release: The Materials Can Be Designed For Controlled Drug Release. Common Materials: Lipids (e.g. Liposomes), Polymers (e.g. PLGA, PGE), Metals (e.g. Gold, Silver), Ceramic (e.g. Silica).[39]

5.7] Surface Chemistry and Modifications
i) Surface Charge: They Influences Nanoparticle Interaction With Cells and Biomolecules.

ii) Surface Hydrophobicity: Affects Nanoparticle Stability and Cellular Uptake.

iii) Surface Functional Groups: Enable Targeting and Drug Conjugation.

5.8] Surface Functionalization
i) PEGylation: Enhances Nanoparticle Stability and Biocompatibility.

ii) Ligand Conjugation: Enables Active Targeting and Cellular Uptake.

iii) Polymer Coating: Controls Drug Release and Nanoparticle Interactions.[40]

5.9] Scalable Production
Scalability and Manufacturing in Pharmaceutical Nanotechnology Refers to The Ability to Produce Nanoparticles in Large Quantities While Maintaining Their Quality and Consistency.

i) Scalability: Ensuring Consistent Nanoparticle Size, Shape, and Surface Properties During Large-scale Production. Scaling Up Synthesis Methods While Maintaining Nanoparticle Uniformity and Stability.

ii) Processing: Optimizing Good Manufacturing Practice (GMP) Guidelines to Ensure Quality Control and Regulatory Compliance. Employing Continuous Flow Synthesis and Microfluidics For Efficient and Scalable Nanoparticles Production.[41]

5.10] Product Uniformity
Stability and Stability Period are Crucial Design Considerations in Pharmaceutical Nanotechnology.

5.11] Stability

i) Physical Stability: Maintenance of Nanoparticle Size, Shape and Aggregation State.

ii) Chemical Stability: Prevention of Degradation, Hydrolysis or Oxidation of Nanocarriers or Cargo.

iii) Biological Stability: Minimization of Interactions with Biomolecules, Immune Responses or Toxicity.

5.12] Shelf Life

i) Storage Conditions: Temperature, Humidity, Light Exposure and Packaging.

ii) Formulation Factors: pH, Ionic Strength and Excipients Interactions.

iii) Nanoparticle Characteristics: Size, Surface Charge and Materials Properties.[42]

Design Consideration to Enhance Stability and Shelf Life
iv) Material Selection: Choose Biocompatible, Non-toxic Materials with Suitable Physiochemical Properties.

v) Formulation Optimization: Balance Nanoparticle Characteristics, Excipients and Storage Conditions.

vi) Sterilization and Packaging: Ensure Proper Sterilization Techniques and Packaging Materials to Prevent Contamination and Degradation.

vii) Quality Control: Implement Rigorous Testing and Monitoring Protocols to Detect Instability or Degradation. By Addressing These Factors, Pharmaceutical Nanotechnology Products Can Achieve Optimal Stability and Shelf Life, Ensuring Efficacy and Safety for Patients.[43]

6. CONCLUSION

Numerous Nanodrugs Have Being Clinically Employed For Dual Purposes of Diagnosis and Treatment are Being Investigated for Various Indications in Clinical Trials. Nanoparticles also Have the Benefits of Being More Adequate for Intravenous Administration than Conventional Microparticles. The Typical Oral or Injectable Medicines Now Accessible for Use are Not.

Necessarily Provides in the Most suitable Formulations. Nanoparticles Have Been Shown to be Effective in Treating Diseases Such as Cancer, Tuberculosis and Alzheimer's and are Being Investigated for Use in Vaccines and Other Applications. The Nanoparticles Can Increase Drug Absorption and Bioavailability.[44,45,46,47,48]

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