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Pharmaceutical application of nanoparticles in drug delivery system

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ABSTRACT

Nanoparticles are of current interest because of an emerging understanding of their possible effects on human health and environmental sustainability, and owing to the increasing output of man-made nanoparticles into the environment. Recent advances in the field of nanotechnology have allowed the manufacturing of elaborated nanosized particles for various biomedical applications. The rapid advancement of nanotechnology has raised the possibility of using engineered nanoparticles that interact within biological environments for treatment of diseases. Nanoparticles interacting with cells and the extracellular environment can trigger a sequence of biological effects Nanoparticles have been developed as an important strategy to deliver conventional drugs, recombinant proteins, vaccines and more recently nucleotides. Nanoparticles modify the kinetics, body distribution and drug release of an associated drug. Other effects are tissue or cell specific targeting of drugs and the reduction of unwanted side effects by a controlled release. Therefore nanoparticles in the pharmaceutical biotechnology sector improve the therapeutic index and provide solutions for future delivery problems for new classes of so called biotech drugs including recombinant proteins and oligonucleotides. This paper aims to review various applications of nanoparticles as carrier system in the field of pharmaceuticals

Keywords: Nanoparticles, drug delivery, carrier systems.

INTRODUCTION

Nanoparticles are of current interest because of an emerging understanding of their possible effects on human health and environmental sustainability, and owing to the increasing output of man-made nanoparticles into the environment. Nanoparticles are used in many different applications and created by many different processes. Their measurement and characterization pose interesting analytical challenges. [1]. Particles having diameter in range between 10-100 nm are known as Nanoparticles. They are used as targeted delivery system for delivery of small and large molecules by changing their pharmacodynamics and pharmacokinetic properties. [2].They can be defined as system which contain active ingredient dissolved, encapsulated or adsorbed in matrix material which are used as target delivery system.[3].To see the effect of drug in target tissue, to increase stability against degradation through enzymes and for solubilization at intra-vascular route nanoparticles have been used [4].During the designing of nanoparticle some control has to take in care such as their release pattern, their size and surface properties which determine site-specific action at optimal rate with right dose regimen [5].Nanoparticles are sub-nano sized colloidal structure of synthetic or semi synthetic polymer .The first reported nanoparticles were based on non-biodegradable polymeric system [6] (polyacrylamide, polymethyl-methaacrylate, polystyrene).The polymeric nanoparticles can carry drug(s) or proteineous substances, i.e. antigen(s). These bioactives are entrapped in polymer matrix as particulates or solid solution or may bound to particle surface by physical adsorption or chemically. The drug(s) may be added during preparation of nanoparticle or to the previously prepared nanoparticles. The term particulates is

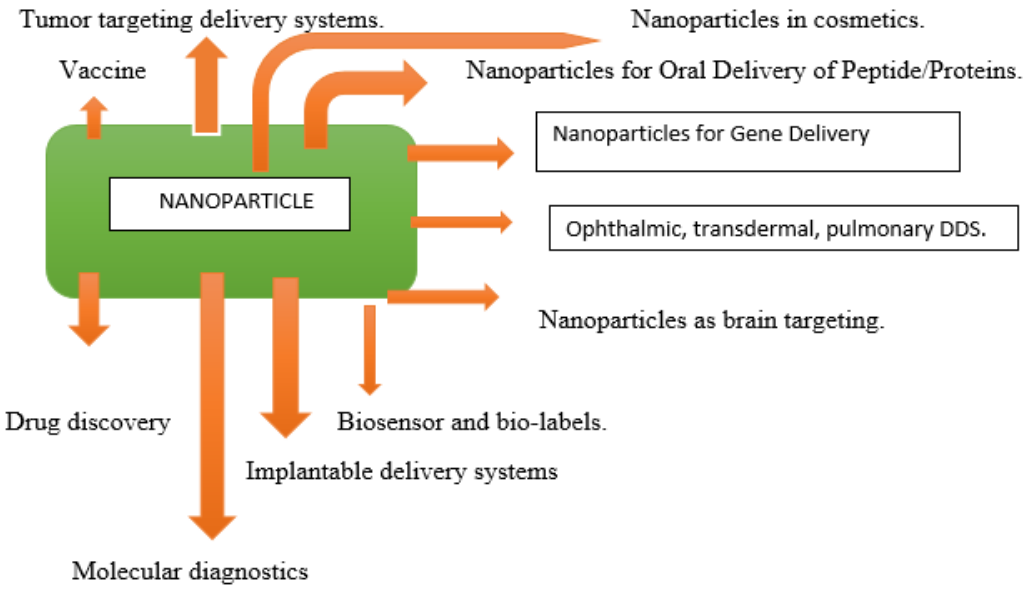
suggestively general and doesn't account for morphological and structural organization of system. Nano medicine is an emerging field of medicine with novel applications.[7].

Advantages of nanoparticles :- They are suitable for different routes of administration, Carrying capacity of nanoparticles is high, Shelf-stability of drug increases, Ability to sustain and control drug release patterns, Suitable for combination therapy where two or more drug can be co-delivered, Both hydrophobic and hydrophilic drug can be incorporated, System increases the bioavailability of drugs, Imaging studies can be done by utilizing them, It is used for targeted drug delivery of drugs, Development of new medicines which are safer.[8,9,10]

Disadvantages of nanoparticles: -The manufacturing costs of nanoparticle are high which result in overall product cost, Solvents are toxic in nature which is used in the preparation process, Can start immune response and allergic reactions in body, Extensive use of poly (vinyl alcohol) as stabilizer may have toxicity issues, Nanoparticles are difficult to handle in physical form because particle-particle aggregation occurs due their small size and large surface area. [11, 12, 13].

Challenges for formulation and delivery: - Of course, the challenges are manifold; basicallyone can differentiate between problems being very often related to these drugs and problems being more related specifically to a molecule, e.g. conformation issues. Problems frequently occurring with many drugs are: Poor solubility, insufficient in vitro stability (shelf life), too low bioavailability, Too short in vivo stability (half-life), Strong side effect, need for targeted delivery, Regulatory issues/hurdles, Lack of large scale production[14] .Various types of nanoparticle as delivery system mentioned in Table no. 1

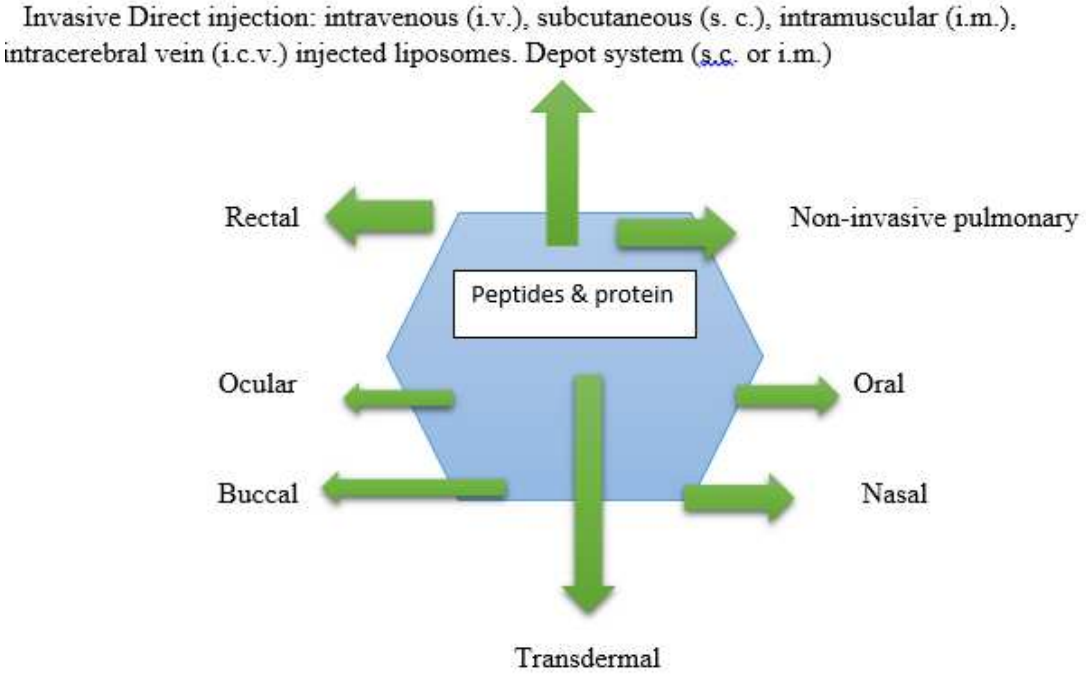
Application of nanoparticles in pharmaceutical field:-



Nanoparticles as a drug delivery system for peptides and proteins: -The increasing number of new molecules of biotechnological origin such as monoclonal antibodies, hormones and vaccines, as well as their therapeutic potential, makes protein delivery an important area of research. [27]. Protein stability is the balancing result between destabilizing and stabilizing forces. The formation and stability of the secondary, tertiary and quaternary structures of proteins are based on weak non-covalent interactions (e.g. electrostatic interactions, hydrogen bonding, van der Waals forces and hydrophobic interactions). Disruption of any of these interactions will shift this delicate balance and destabilize the proteins [28, 29]. Therefore, the chemical and physical stability of proteins can be compromised by environmental factors such as pH, ionic strength, temperature, high pressure, non-aqueous solvents, metal ions, detergents, adsorption, and agitation and shearing. Solid lipid particulate systems such as solid lipid nanoparticles (SLN), lipid microparticles (LM) and lipospheres have been sought as alternative carriers for therapeutic peptides,

proteins and antigens. The research work developed in the area confirms that under optimized conditions they can be produced to incorporate hydrophobic or hydrophilic proteins and seem to fulfill the requirements for an optimum particulate carrier system. Proteins and antigens intended for therapeutic purposes may be incorporated or adsorbed onto SLN, and further administered by parenteral routes or by alternative routes such as oral, nasal and pulmonary. Formulation in SLN confers improved protein stability, avoids proteolytic degradation, as well as sustained release of the incorporated molecules. Important peptides such as cyclosporine A, insulin, calcitonin and somatostatin have been incorporated into solid lipid particles. [27].

Delivery routes and novel technologies for therapeutic peptides and proteins are:-

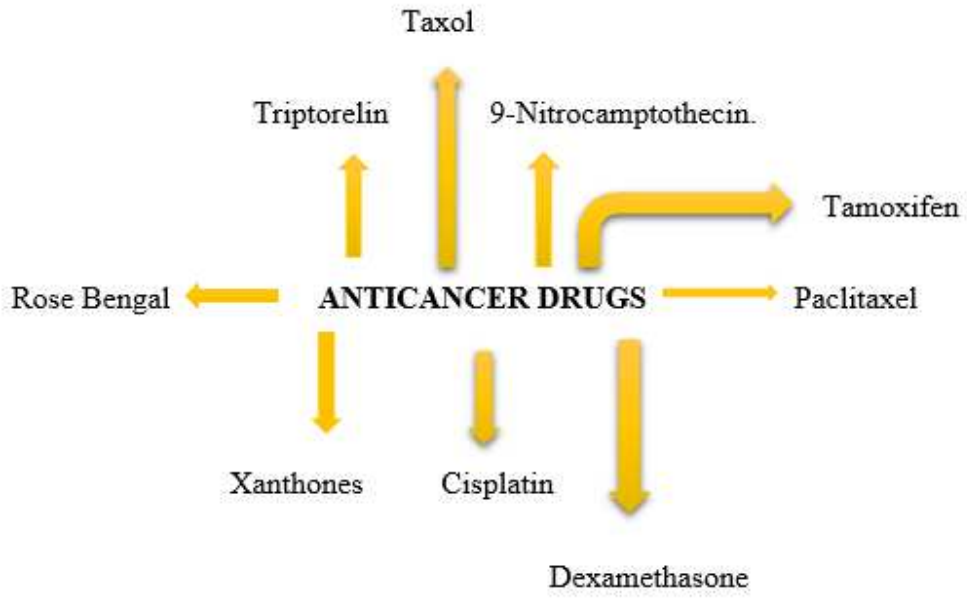


Tumor targeting delivery systems:-The rationale of using nanoparticles for tumor targeting is based on following characteristics:

1) Nanoparticles will be able to deliver a concentrate dose of drug in the vicinity of the tumor targets via the enhanced permeability and retention effect or active targeting by ligands on the surface of nanoparticles.

2) Nanoparticles will reduce the drug exposure of healthy tissues by limiting drug distribution to target organ. Studies show that the polymeric composition of nanoparticles such as type, hydrophobicity and biodegradation profile of the polymer along with the associated drugs molecular weight, its localization in the nanospheres and mode of incorporation technique, adsorption or incorporation, have a great influence on the drug distribution pattern in vivo. The exact underlying mechanism is not fully understood but the bio distribution of nanoparticles is rapid, within hour to 3 hours, and it likely involves mononuclear phagocytic system (MPS) and endocytosis/ phagocytosis process. Such propensity of MPS for endocytosis/phagocytosis of nanoparticles provides an opportunity to effectively deliver therapeutic agents to these cells. This biodistribution can be of benefit for the chemotherapeutic treatment of MPS richorgans/tissues localized tumors like hepatocarcinoma, hepatic metastasis arising from digestive tract or gynecological cancers, bronchopulmonary tumors, primitive tumors and metastasis, small cell tumors, myeloma and leukemia. [30, 31].

Encapsulation of various anticancer drugs in nanoparticles:-



Nanoparticles in dermatology: - Recent advances in the field of nanotechnology have allowed the manufacturing of elaborated nanometersizedparticles for various biomedical applications. Controlled drug release to skin and skin appendages, targeting of hair follicle-specific cell populations, transcutaneous vaccination and transdermal gene therapy are only a few of these new applications. Carrier systems of the new generation take advantage of improved skin penetration properties, depot effect with sustained drug release and of surface functionalization (e.g., the binding to specific ligands) allowing specific cellular and subcellular targeting. Drug delivery to skin by means of microparticles and nanocarriers could revolutionize the treatment of several skin disorders. [32].

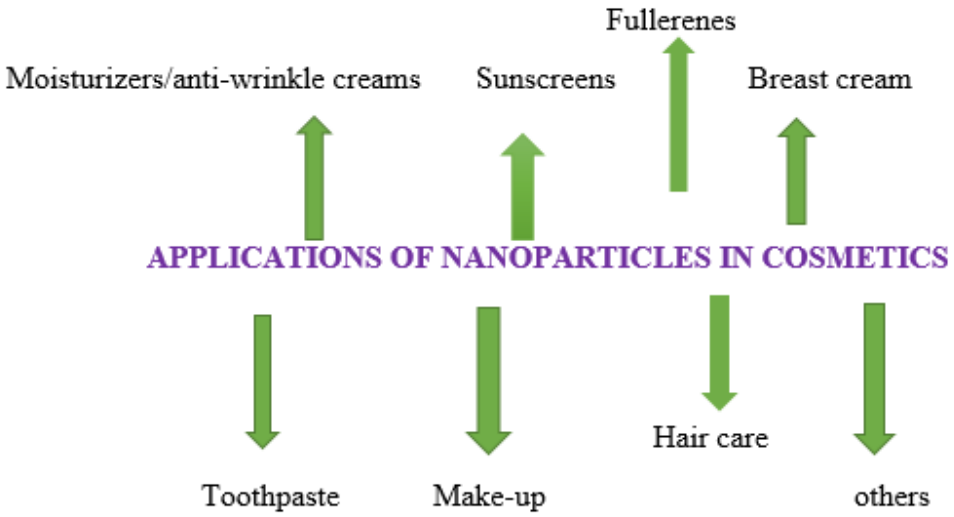
Dermal drug delivery: - Dermal drug delivery with (lipid nanoparticle) LN is of particular interest for diseases of the HF (hair follicle) in order to increase the local bioavailability of API at their drug target. Several targets were identified for drugs in the HF; for instance, isotretinoin causes a cell cycle arrest and apoptosis in sebocytes [33], minoxidil stimulates the vascular endothelial growth factor and prostaglandin synthesis in the dermal papilla [34], and cyclosporine A supports hair epithelial cell growth [35]. In dermal therapy, the main goal is to circumvent systemic adverse effects by local administration of the API. Generally, severe disease states are treated systemically; therefore, one main unmet medical need remains effective topical targeting. In general, follicular targeting remains one of the most promising concepts in current topical drug delivery applications apart from epidermal penetration and manipulation of SC lipid organization [36].

Topical application:-Regarding the regularity aspect, topical application is relatively unproblematic. The major advantages for topical products are the protective properties of SLN for chemically labile drugs against degradation and the occlusion effect due to film formation on the skin. Especially in the area of cosmetics there are many compounds such as retinol or vitamin C which cannot be incorporated because of the lack of chemical stability. Incorporation of retinol is only possible when applying certain protective measures during production (e.g. noble gasing) and using special packing materials (e.g. aluminium) [37, 38].

Transdermal drug delivery: - The smallest particle sizes are observed for SLN dispersions with low lipid content (up to 5%). Both the low concentration of the dispersed lipid and the low viscosity are disadvantageous for dermal administration. In most cases, the incorporation of the SLN dispersion in an ointment or gel is necessary in order to achieve a formulation which can be administered to the skin. The incorporation step implies a further reduction of the lipid content. An increase of the solid lipid content of the SLN dispersion results in semisolid, gel-like systems, which might be acceptable for direct application on the skin [38, 39].In general, alternative dosage forms to transdermal therapeutics systems are hard to establish due to a limited permeation rate which also applies to LN.

Prospective approaches which are in the focus of research are the introduction of enhancers, iontophoresis, and micro needles which are all invasive. [40].

Nanoparticle in cosmetics: - The present review aims to study a promising area of Nanoparticles used in various cosmetic products like Deodorant, Soap, Toothpaste, Shampoo, Hair conditioner, Anti-wrinkle cream, Moisturizer, Foundation, Face powder, Lipstick, Blush, Eye shadow, Nail polish, Perfume and After-shave lotion etc. In particular, NLCs have been identified as a potential next generation cosmetic delivery agent that can provide enhanced skin hydration, bioavailability, stability of the agent and controlled occlusion. [41].



1. Sunscreens:-
UV filters, such as titanium dioxide and zinc oxide, are used in nano form rather than bulk form to make the sunscreen transparent rather than white. It is also claimed that they are more effective when used in nano form. [42].
2. Breast cream:-
St Herb Nano Breast Cream claims it is a combination of “nanotechnology and the timeless Thai herb, Pereira Mirifica” and thatnoisome “expands the cellular substructure and development of the lobules and alveoli of the breasts”, [43].
3. Hair care:-
RBC Life Science’s Nanoceuticals Citrus Mint Shampoo and Conditioner are made with Nano Clusters TM, “nanoclusters to give hair a healthy shine”. [44]
4. Make-up:-
Serge Lutens Blusher’s Nano Dispersion technology “creates an extremely fine and light powder with extraordinary properties: excellent elasticity, extreme softness and light diffusion. [45]
5. Moisturizers/anti-wrinkle creams:-
Lancôme Hydra Zen Cream with “nano-encapsulated Triceramide renew skin’s healthy look”; L’Oreal Revitalift Double Lifting anti-wrinkle cream is their “first double-action cream that instantly re-tautens the skin and reduces the appearance of wrinkles”, and contains Nanosomes of Pro-Retinol A. [46].
6. Toothpaste:-
Sangi’sApagard claims to be the world’s first ‘remineralizing’ toothpaste, promoting oral health by supporting natural healing, using “Nanoparticles hydroxyapatite”, “the same substance as our teeth”; Ace Silver Plus Nano silver toothpaste is manufactured.’[47]
7. Fullerenes:-
New types of materials can be produced using nanotechnology, such as carbon fullerenes. It is claimed that these tiny carbon spheres have anti-aging properties. [48]
8. Others
a) Nano emulsions and nanosomes – used to preserve active ingredients, such as vitamins and anti-oxidants, and their lightness and transparency.

b) Other materials used in nano size – a whole range of materials can be used in nano size in order to give them different properties when compared with their larger form. We found, for example, an 'energizing' moisturizer using nano gold and products using nano silver because of its anti-bacterial properties [49, 50].
c) SLN can act as a physical UV blocker them and are able to improve the UV protection in combination with organic sunscreens such as 2-hydroxy-4-methoxy benzophenone which allows a reduction of the concentration of the UV absorber [51, 52].
d) Nanogold Facial Mask [53].

Nanoparticle for gene delivery: -Gene therapy can be defined as the transfer of genetic material, a functional gene or DNA/ribonucleic acid (RNA) fragment into specific cells to elicit a desired therapeutic phenotype in order to reduce symptoms or treat human diseases [54]. There are two categories of somatic cell gene therapy, according to genetic material delivery method, ex vivo or in vivo. Ex vivo approach involves tissue biopsy, followed by cells [55]. Finally, modified cells are returned to the body. In vivo approach consists in direct application of genetic material into cells, e.g., direct tissue injection or modification of culture cells for posterior implantation [56, 57]. These therapies have an ample potential and have been heavily investigated during the past 30 years. Polynucleotid**e** vaccines work by delivering genes encoding relevant antigens to host cells where they are expressed, producing the antigenic protein within the vicinity of professional antigen presenting cells to initiate immune response.[58] Such vaccines produce both humoral and cell-mediated immunity because intracellular production of protein, as opposed to extracellular deposition, stimulates both arms of the immune system. The key ingredient of polynucleotide vaccines, DNA, can be produced cheaply and has much better storage and handling properties than the ingredients of the majority of protein-based vaccines. Hence, polynucleotide vaccines are set to supersede many conventional vaccines particularly for immunotherapy. However, there are several issues related to the delivery of polynucleotides, which limit their application. [59] These issues include efficient delivery of the polynucleotide to the target cell population and its localization to the nucleus of these cells, and ensuring that the integrity of the polynucleotide is maintained during delivery to the target site. Nanoparticles loaded with plasmid DNA could also serve as an efficient sustained release gene delivery system due to their rapid escape from the degradative endolysosomal compartment to the cytoplasmic compartment. Hedley et al. reported that following their intracellular uptake and endolysosomal escape, nanoparticles could release DNA at a sustained rate resulting in sustained gene expression. This gene delivery strategy could be applied to facilitate bone healing by using PLGA nanoparticles containing therapeutic genes such as bone morphogenic protein [60]. (Gelatin nanoparticles) GNPs have several advantages as a non-viral gene delivery vector. They can be conjugated to moieties that stimulate receptor-mediated endocytosis, multiple plasmids can be encapsulated and the bioactivity of the encapsulated DNA could be improved by preventing digestion by nucleases and by using long-circulating PEGylated nanoparticles [61, 62]. Nucleic acids can be loaded onto GNPs through physical encapsulation, electrostatic attraction or complexation with surface modifying groups [63], were the first to develop type B GNPs as noncondensing gene delivery systems. The negatively charged type B gelatin at neutral pH 7.0, can physically encapsulate reporter and therapeutic nucleic acid constructs as opposed to positively charged lipids and polymers that electrostatically condense DNA. The physically encapsulated plasmid DNA (pDNA) in a hydrogel-type matrix is protected in the systemic circulation and upon cellular transport. Additionally, the released pDNA has a supercoiled structure at the nuclear membrane which is critical for efficient uptake and transfection [64]. In other instances, the negatively charged nucleic acids can be adsorbed onto the surface of GNPs by modifying the surface of gelatin with a quaternary amine (e.g. cholamine) to increase ionic interactions.Some examples of gene therapy applications are mentioned in Table no.2.

Nanoparticles in ocular delivery systems: -Many investigations have been made to use nanoparticles for prolonged release of drugs to the eye. The basic problem of ophthalmologic formulation is the fast removal from the eye, which implies clearance of the applied drug through the nose. It could be shown for nanoparticles that an increased adhesiveness is available leading to higher drug levels at desired site of action. However, the basic problem was that the nanoparticles are of limited toxicological acceptance. It was shown by Gasco that SLN have a prolonged retention time at the eye. This was confirmed by using radiolabeled formulations and γ-scintigraphy. The lipids of SLN are easy to metabolize and open a new ways for ophthalmological drug delivery without impairing vision [73].

Nanoparticles as per-oral drug delivery: - Per oral administration forms of SLN may include aqueous dispersions or SLN loaded traditional dos-age forms, e.g. tablets, pellets or capsules. The microclimate of the stomach favors particle aggregation due to the acidity and high ionic strength. It can be expected, that food will have a large impact on SLN performance [74]. The plasma levels and body distribution were determined after administration of CA–

SLN suspension versus a CA(Cyclosporin) solution (CA-SOL). Two plasma peaks were observed after administration of CA–SLN. The first peak was attributed to the presence of free drug; the second peak can be attributed to controlled release or potential gut uptake of SLN. These two peaks were also found in the total CA concentration–time profiles of all measured organs. It was also found that the incorporation into SLN protected CA from hydrolysis. The conclusion from this study was that SLN are a promising sustained release system for CA and other lipophilic drugs after oral administration. Increased bioavailability and prolonged plasma levels have been described after per oral administration of cyclosporine containing lipid nano dispersions to animals [75].

Implantable delivery systems: - Nanoparticles can act as the delivery systems by virtue of its size, controlled an approximately zero order kinetics, otherwise they may cause toxicity when compared to I.V. Carriers are liposome, ethosome and transferosome. These help in minimizing peak plasma levels and reduce risk of adverse reactions, allow for more predictable and extended duration of action, reduce the frequency of re-dosing and improve patient acceptance and compliance [76].SLN have been administered intravenously to animals. Pharmacokinetic studies of doxorubicin incorporated into SLN showed higher blood levels in comparison to a commercial drug solution after i.v. injection in rats. Concerning the body distribution, SLN were found to cause higher drug concentrations in lung, spleen and brain, while the solution led to a distribution more into liver and kidneys [77]. Parenteral application is a very wide field for SLN. Subcutaneous injection of drug loaded SLN can be employed for commercial aspect, e.g., erythropoietin (EPO), interferon-β. Other routes are intraperitoneal and also intra-articular. Intraperitoneal application of drug-loaded SLN will prolong the release because of the application area. In addition, incorporation of the drug into SLN might reduce irritancy compared to injecting drug micro particles [78].

Nanoparticles as Pulmonary drug delivery:-
A very interesting application appears to be the pulmonary administration of SLN. SLN powders cannot be administered to the lung because the particle size is too small and they will be exhaled. A very simple approach is the aerosolization of aqueous SLN dispersions. The important point is that the SLN should not aggregate during the aerosolization. The aerosol droplets were collected by collision of aerosol with a glass wall of a beaker. This basically demonstrates that SLN are suitable for lung delivery. After localization into the bronchial tube and in the alveoli, the drug can be released in a controlled way from the lipid particles [78].

Nanoparticles as carriers for nasal vaccine delivery: - At present, there is considerable excitement within the nanotechnology field with regard to the potential use of nanosystems as carriers for mucosal vaccine delivery [79].Many diseases, such as influenza, respiratory syncytial virus infection, measles and meningitis, are associated with the entry of microorganisms across the respiratory mucosal surfaces. Therefore, upon vaccination against these diseases, it is highly desirable to obtain a local mucosal defense at the entry pathway of the corresponding pathogens, that is, the primary site of infection, as it eliminates the risks of person-to-person and environmental infection [80].This can be accomplished by the delivery of vaccines by the nasal route, since both mucosal and systemic (i.e., humoral and cell-mediated) immune responses can be induced, especially if the vaccine is adjuvanted by an immune stimulator or a delivery system. In addition, nasally administered vaccines induce secretory mucosal immunoglobulin (Ig)A [81]. Various studies using chitosan nanoparticles and chitosan–DNA complexes as vaccine carriers for nasal administration is mentioned in Table No.3

Nanoparticle as a Drug discovery: -Nanoparticles helps in identification and validation of target by identifying the protein present on the surface or target surface. Nanoparticles will enhance drug delivery process, through miniaturization, automation, speed and reliability of assays. Single walled nanotubes are successfully used to identify surface protein of pathogen [86]. Quantum dots- track individual glycine receptors and to analyze their dynamics in the neuronal membrane of living cells, for periods ranging from milliseconds to minutes. Gold nano particles, nanobodies (smallest, available, intact antigen-antibody fragments) produced by ablynx are some commonly used nanomaterials in diagnosis. The pharmaceutical nanotechnology is used in the biodetection of pathogens in humans, separation and purification of molecules and cells and detoxifying agents. Future Nano machine (respirocyte) is the nano-on-board minicomputer that can be used for detection of disease causing marker or antigen, to view the diseased site and to deliver the therapeutic agent at the site [87].

Nanoparticle in Molecular diagnostics: (molecular imaging):- It is representing, characterizing and quantifying sub cellular biological processes include gene expression, protein-protein interaction, signal transduction, cellular metabolism [88]. Theyare used in magnetic resonance imaging, optical imaging, ultrasonic imaging and nuclear imaging. Other applications are specific labeling of cells and tissues useful for long-term imaging, multicolor

multiplexing, dynamic imaging of sub cellular structures and fluorescence resonance energy transfer (FRET) and magnetic resonance imaging (MRI) [89]. MRI agents are replaced by nanomaterials like dendrimers, quantum dots, carbon nanotubes and magnetic nanoparticles. They are very efficient, stable, intense, clearer image due to high intensity, photo stability, resolution, resistance [90].Quantum dots, iron oxide nanocrystal and metallic nanoparticles.

Nanoparticle as Biosensor and bio-labels:-These tools are employed for determination of various pathological proteins and physiological-biochemical indicator associated with disease or disrupted metabolic conditions of body. Biosensor is a measurement system that consists of a probe with a sensitive biological recognition element or bioreceptor, a physiochemical detector component and a transducer to amplify and transducer these signals into measurable form. A Nano biosensor or nanosensor is a biosensor that has dimensions on the nanometer size scale. Biosensors are used in target identification, validation, assay development, ADME, toxicity determination. [91]

Table no. 1: Various types of nanoparticles applied in the drug delivery system

Sl.no	Type of Nanoparticles	Material used	Applications	References
1.	Nano suspensions and Nanocrystals	Drug powder is dispersed in surfactant solution	Stable system for controlled delivery of poorly soluble drug	[15]
2.	Solid lipid Nanoparticles	Melted lipid dispersed in Aqueous surfactant	Least toxic and more stable Colloidal carrier systems as alternative materials To polymers	[16]
3.	Polymeric nanoparticles	Biodegradable polymers	Controlled and targeted drug delivery	[17]
4.	Polymeric micelles	Amphiphilic block copolymers	Controlled and systemic Delivery of water insoluble Drugs	[18]
5.	Magnetic Nanoparticles	Magnetite Fe2O3, Meghe Mite coated with dextran	Drug targeting diagnostics to in medicine	[19]
6.	Carbon Nanotubes	Metals, semiconductors	Gene and DNA delivery	[20]
7.	Liposomes	Phospholipid vesicles	Controlled targeted drug Delivery	[21]
8.	Nanoshells	Dielectric core and metal shell	Tumor targeting	[22]
9.	Ceramic Nanoparticles	Silica, alumina, titania	Drug and biomolecule Delivery	[23]
10.	Nano pores	Aerogel, which is produced by cell gel chemistry	Controlled release drug Carriers	[24]
11.	Nano wires	Silicon, cobalt, gold or Copper based nanowires	Transport electron in nano Electronics	[25]
12.	Nano films	polypeptides	Systemic or local drug Delivery	[26]

Table No.2 Various application of nanoparticles in gene therapy

Pathology	References
Acute and chronic wounds	[65]
Traumatic brain injury	[66]
Diabetes	[67]
Huntigton disease	[67]
Parkinson disease	[67, 68, 69]
Ischemia	[67]
Cancer	[70, 71, 72]

Table No. 3: Nanoparticle as Carriers in Nasal Vaccine delivery

Carrier system	Antigen	Species	Result	References
Nanoparticles	Tetanus toxoid	Mice, rats	Chitosan nanoparticles elicited long-lasting immune responses significantly higher than those of control solutions	[82]
Nanoparticles	Ovalbumin	Rats	Greater response against CH-particle	[83]
Nano complex	RSV antigens expressed from pDNA	Mice	Expression of encoded protein antigens in the lungs and significant reduction of viral titers and viral antigen load after acute RSV infection (Respiratory syncytial virus).	[84]
Nano complex	RSV antigens expressed from pDNA	Mice	Following RSV challenge, a significant reduction in the virus load in the lungs	[85]

CONCLUSION

Nanotechnology-enabled drug delivery is opening prospective future in pharmaceutics. The upcoming of nanotechnology have a significant impact on drug delivery sector, affecting just about every route of administration

from oral to injectable. The present pharmaceutics is often characterized by poor bio-availability which far too often results in higher patient costs and inefficient treatment but also, more importantly, increased risks of toxicity. Nanotechnology focuses on the very small and it is uniquely suited to creating systems that can better deliver drugs to tiny areas within the body. Nano enabled drug delivery also enable drugs to permeate through cell walls, which is important to the expected growth of genetic medicine over the next few years. The payoff for doctors and patients from nanotechnology-enabled drug delivery should be lower drug toxicity, reduced cost of treatments, improved bioavailability and an extension of the economic life of proprietary drugs.

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