Düzce University Journal of Science & Technology

Review Article

Drug Delivery Based on Nanoparticulate Systems

Kemal ÇETİN [a,b*], Koray ŞARKAYA [c]

[a] *Department of Biomedical Engineering, Faculty of Engineering, Necmettin Erbakan University, Konya, TURKEY*
[b] *Science and Technology Research and Application Center (BITAM), Necmettin Erbakan University, Konya, TURKEY*
[c] *Department of Chemistry, Faculty of Science, Pamukkale University, Denizli, TURKEY*
** Corresponding author's e-mail address: kcetin@erbakan.edu.tr*
DOI: 10.29130/dubited.1469423

ABSTRACT

The administration route of an active ingredient and the materials used to deliver it are as important as the synthesis of that active ingredient. For the treatment to be effective, the active ingredient must be present in the right amount and in the right place at the right time. Therefore, researchers have been studying a wide variety of drug delivery systems, taking into account the route of administration of the drug, its half-life, and its effective and toxic amounts. Because of its numerous benefits, nanotechnology has attracted attention in pharmaceutical research as well as many other fields. Nanoparticles have the potential to disperse hydrophobic drugs in an aqueous solution, deliver drugs to the targeted site, and thus selectively direct therapeutic agents such as antineoplastic drugs. This study provides a detailed discussion of the many inorganic, polymeric, and lipid-based nanoparticulate systems designed for drug delivery.

Keywords: *Drug delivery systems, Nanomedicine, Nanoparticles, Nanotechnology*

Nanopartikül Sistemlere Dayalı İlaç Taşıma

ÖZET

Bir etkin maddenin veriliş yolu ve vermek için kullanılan malzemeler, o etkin maddenin sentezi kadar önemlidir. Tedavinin etkili olabilmesi için etken maddenin doğru miktarda ve doğru zamanda doğru yerde bulunması gerekir. Bu nedenle araştırmacılar, ilacın veriliş yolunu, yarı ömrünü, etkili ve toksik miktarlarını dikkate alarak çok çeşitli ilaç taşıyıcı sistemler üzerinde çalışmaktadır. Nanoteknoloji, sayısız faydaları nedeniyle pek çok alanda olduğu gibi farmasötik araştırmalarda da ilgi çekmektedir. Nanopartiküller, hidrofobik ilaçları sulu bir çözelti içinde dağıtma, ilaçları hedeflenen bölgeye iletme ve dolayısıyla antineoplastik ilaçlar gibi terapötik ajanları seçici olarak yönlendirme potansiyeline sahiptir. Bu çalışma, ilaç dağıtımı için tasarlanmış birçok inorganik, polimerik ve lipit bazlı nanopartikül sistemin ayrıntılı bir tartışmasını sunmaktadır.

Anahtar Kelimeler: *İlaç taşıyıcı sistemler, Nanotıp, Nanopartiküller, Nanoteknoloji*

Received: 16/04/2024, Revised: 22/05/2024, Accepted: 28/05/2024

I. INTRODUCTION

Drug delivery systems (DDSs) regulate both the location and speed of release of a drug throughout the body. DDSs are designed to measure drug levels and extend the effects of the therapeutic agents over time. As required, DDSs can also be triggered by outside stimuli such as pH, temperature, magnetic field etc., to release the therapeutic agents to the media as needed. Studies in the field of DDSs can be classified into three main classes: delivery routes, e.g., oral, pulmonary, and transdermal; types of delivery systems, e.g., inorganic, lipid-based, and polymeric; and targeting strategies, e.g., surface modifications [1].

Nanotechnology covers scientific studies, engineering applications, and technology, particularly at sizes of 1 to 100 nm. By altering the characteristics of matter, nanoscience and nanotechnology enable the development of novel and inventive materials in various areas including biomedical engineering, chemistry, physics, electronic engineering, environmental engineering, and so on [2], [3], [4]. Nanoparticulate-DDSs (nano-DDSs) carry out significant advantages such as targeting drugs with low bioavailability directly to the desired area, more efficient imaging for diagnosis, and higher accuracy detection of tumoral tissues [5]. Nano-DDSs enable drugs to reach the target site, i.e., organ, tissue, or cells in high concentrations safely, controlled, and effectively [6].

II. NANOPARTICLES AS DRUG DELIVERY SYSTEMS

Nanoparticulate DDSs (nano-DDSs) can be classified as organic nanoparticles e.g., dendrimers, liposomes and niosomes, inorganic nanoparticles e.g., metal nanoparticles, and carbon-based nanoparticles e.g., graphenes, carbon nanotubes (Figure 1).

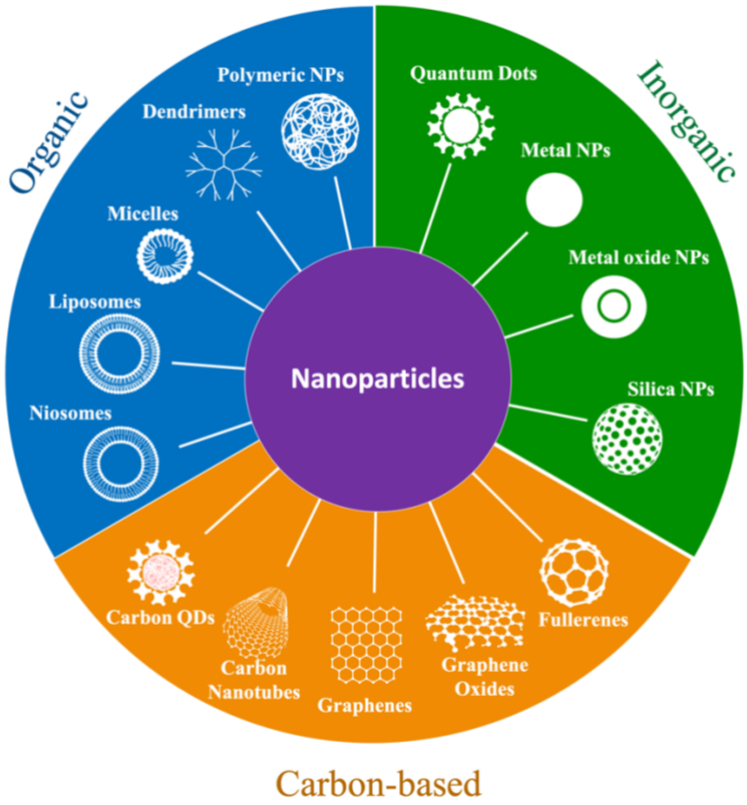

Figure 1. *Schematic diagram of different types of nanoparticles (NPs).*

A. POLYMERIC NANOPARTICLES

In the intelligent drug delivery discipline, polymeric nanoparticles are part of a wide range of uses as they can efficiently deliver therapeutics to the intended location in the human body [7]. Compared to other compositions, polymeric materials offer the great combination of properties, including stability and high agent loading, control over drug release kinetics, ease of modification to display a variety of surface-attached ligands, and a long history of safe human use for many polymers [8]. A formulation that can deliver the medication in a controlled manner and at a specified location is of primary importance to the researchers [9].

An ideal polymeric nanoparticulate system should have minimum dimensions and high drug-loading capacity [10]. In line with this goal, polymers offer a variety of uses by being divided into two different classes: natural and synthetic. Natural polymers have proven exceptional because of their intrinsic qualities, which include surface modification ease and biocompatibility so that most natural polymers are already found in living things [9]. Oligosaccharides [11], polysaccharaides [12], proteins [13], [14], peptides [15], and genes [16], [17] can be used in DDSs as molecules belonging to the natural polymer class. Polymers such as polylactic acid [18] polycaprolactone [19], polylactic-co-glycolic acid [20], polyethylene glycol [21], 2-hydroxyethyl methacrylate [22], [23], [24] and N-isopropylacrylamide [25] can be frequently used in DDSs as synthetic polymers. Various physicochemical characteristics of polymeric nanoparticles used as DDSs are given in Figure 2.

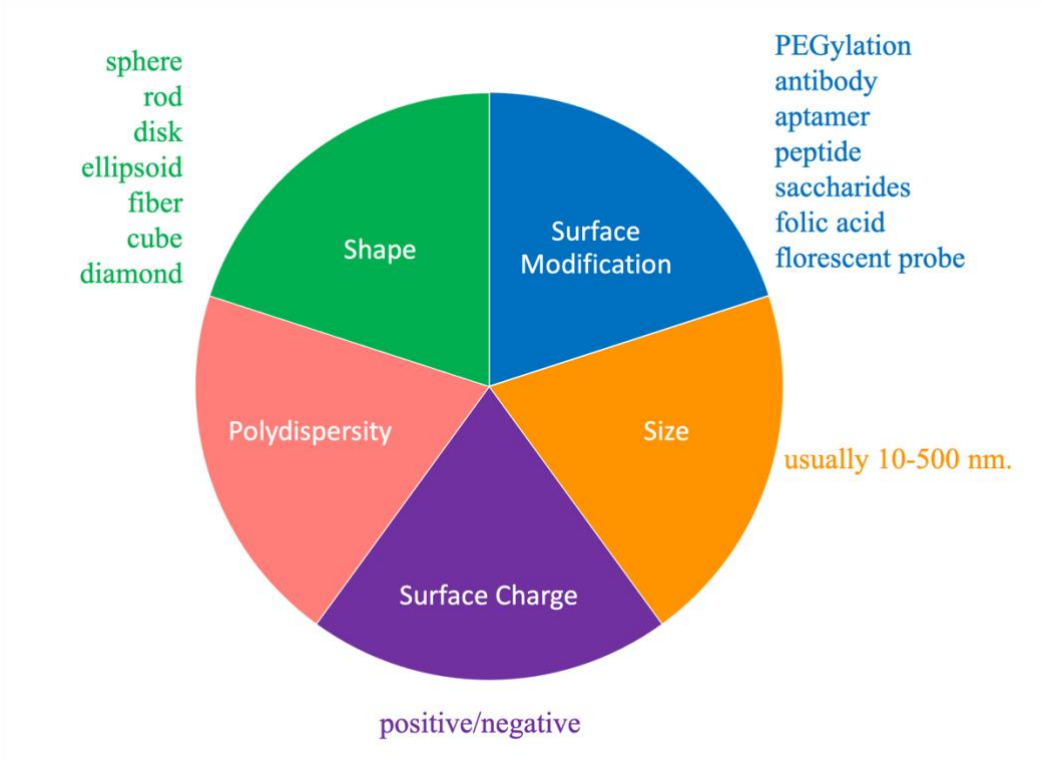

Figure 2. *Different parameters for polymeric nanoparticles utilized as DDSs.*

B. LIPOSOMES

Liposomes are a colloidal spherical structure formed by the self-assembly of amphiphilic lipid molecules such as phospholipids in solution [26]. They are artificial vesicles of various sizes composed of artificial or natural phospholipids [27]. Phospholipids have an amphiphilic nature and form polar shells in aqueous solution due to the hydrophobic effect of hydrophobic acyl chains when exposed to an aqueous environment. This technique has thermodynamic advantages because of hydrogen bonds, van der Waals forces, and other electrostatic interactions [28]. It has a structure similar to the cell membrane, consisting of a lipid bilayer and an aqueous core. Depending on the formulation of liposomes, they can differ in size, lipid composition, and charge [29].

Liposomes have the unique capacity to load and transport molecules with varying solubilities because to their well-organized structure. A liposomal membrane is usually built up by one or more lipid bilayers arranged around an inner aqueous core, with polar head groups facing both the outer and inner aqueous media [27]. Therefore, both lipophilic and hydrophilic drug molecules can be loaded to the liposomes [30]. Hydrophobic molecules can be loaded into the lipid bilayer, while hydrophilic molecules and amphiphilic molecules can be loaded into the inner aqueous core and water/lipid bilayer interface, respectively [31]. Liposomes can be counted as DDSs with many advantages such as biocompatibility, structural versatility, biodegradability, non-toxic, non-immunogenic nature and can change the pharmacokinetic profile of the drugs [32].

The effectiveness of encapsulation of a therapeutic molecule in the liposome depends on the polarity of the drug and its partition coefficient, which determines its location in the liposomal membrane [33]. If the drug is hydrophobic, drug is in the acyl hydrocarbon chain in the liposome. Otherwise, if it is polar/hydrophilic, it tends to be adjacent to the water-lipid interface, in the aqueous core, or near the polar head groups of the liposome [34].

Investigation of drug release from liposomes is usually carried out *in vitro* using a dialysis method [35]. According to this method, the drug molecules are allowed to pass through the membrane of pre-wetted dialysis bags with a predetermined molecular weight limit while the liposomes are trapped within dialysis bags. The release rate from liposomes is determined by monitoring the amount of released drug molecules at various time intervals. [36], [37].

Numerous liposome-based formulations that are either commercially available or conducting clinical trials attest to the efficacy of liposomes as drug carriers [38], [39], [40], [41], [42]. Among drug delivery applications, pH-sensitive liposome design is advantageous for specific cancer cell targeting, increased cellular internalization (inclusion), and rapid intracellular drug release, especially in the face of pH values that can change in various sites including tumor and extracellular environments [43], [44], [45], [46], [47], [48].

C. NIOSOMES

Analogs of liposomes, niosomes (non-ionic surfactant-based vesicles) are closed bilayer structures created by non-ionic amphiphiles (surfactants) in the aqueous medium [49]. As liposomes are built up from neutral or charged double-chain phospholipids, niosomes are created using uncharged single-chain surfactants and solutes [49]. Surfactants in the niosome structure are positioned so that their hydrophilic head parts face inward and their hydrophobic tail parts face each other on the inside. This structure creates two regions in niosomes: hydrophilic and hydrophobic [50]. Niosomes allow the encapsulation of hydrophilic and hydrophobic drugs thanks to their structure's hydrophilic and hydrophobic parts [51].

Niosomes surround the molecule to be encapsulated similarly to liposomes and offer a wide solubility range for the encapsulation process. Niosomes behave *in vivo* similarly to liposomes [52]. In contrast, when mechanical stress is applied, niosomes change shape but are more stable than liposomes. It is not necessary for them to operate in an inert environment [53]. Niosomes can overcome disadvantages of liposomes, including variable phospholipid purity and high cost [54]. However, they can be sterilized using approaches such as Gamma radiation, autoclaving and membrane filtration [55].

Adjusting vesicle composition and temperature can generate niosome structures with spherical, helical, tubular, and polyhedral shapes. While they have an osmotically active and stable structure, they are also flexible [56]. Being stable and flexible, it effectively prevents problems such as leakage during molecule transportation to the target area. It is biocompatible, non-immunogenic, and non-toxic [57]. It is known that niosomes not only protect the drug they encapsulate from mechanical and chemical degradation but also increase the effectiveness of the drug [58].

Niosomes have many advantages using as nanocarrier drug systems. It increases the oral bioavailability of poorly absorbed drugs and increases skin penetration [59]. It is suitable for oral [60], parenteral [61], pulmonary [62], ocular [63] transdermal [64], [65] and topical applications [66], [67].

D. SOLID LIPID NANOPARTICLES

With the benefits of biodegradation and nontoxicity, nanolipid dispersions, which include liposomes, ethosomes, virosomes, and solid lipid nanoparticles (SLNs), are apropriate colloidal carriers for distribution. Compared to liposomes and polymeric nanoparticles, SLNs predominate because of their advantages. For instance, because they degrade naturally, SLNs and nanostructured lipid carriers are not biotoxic and they are also relatively stable [68].

Triglycerides and fatty acids are examples of non-polar lipids that are colloidally dispersed and solid at body and room temperatures. These lipids are known as solid lipids and the use of solid lipids, which significantly lowers the mobility of integrated therapeutic agents into the lipid matrix, is the main benefit of SLNs. Moreover, this keeps particles from coalescing, enhancing stability, limiting drug protuberance into the emulsifier film, and promoting prolonged drug release [69]. Another essential characteristic of SLNs is their absorption by the reticuloendothelial system, which increases the medicines' bioavailability by avoiding first-pass metabolism when taken orally [70]. Additionally, they make surface modification of the carrier easier, which lengthens the duration of blood circulation and improves the pharmacokinetic profile of the medications [71].

Since SLNs are made of solid lipids, they are significant carriers for lipophilic drugs. However, developing SLNs as a vehicle for water-soluble compounds is challenging [72]. As indicated, owing to their low affinity for the lipid matrix, water-soluble chemicals strongly tend to partition into the outer aqueous phase throughout the synthesis process [73]. It has been demonstrated that SLNs systems that target macrophages effectively treat rheumatoid arthritis [74], diabetes [75], psoriasis [76] and autoimmune blood diseases [77]. A schematic illustration of liposome, niosome and SLNs were given in Figure 3.

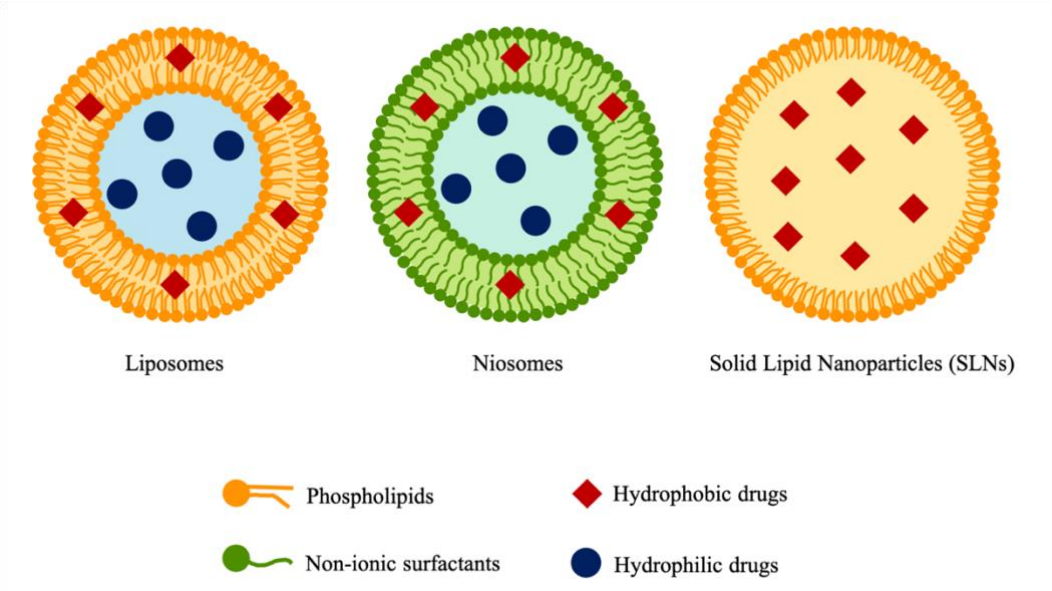

Figure 3. *A schematic illustration of liposome, noisome and solid lipid nanoparticles (SLNs).*

E. METALLIC NANOPARTICLES

Metal-based nanoparticles include many metals and metal oxides such as copper, copper oxide, iron, iron oxide, silver, cobalt and titanium dioxide [78]. Metal oxides have been employed in different areas including, sensor technologies, catalysis, solar cells etc. [79], [80]. It has produced notable advancements, particularly in the medical field, that metallic nanoparticles increase drug therapeutic index through site specificity, avoid multidrug resistance, and efficiently distribute therapeutic agents [81]. Metallic nanoparticles are DDSs for a wide range of therapeutic agents such as peptides, nucleic acids, antibodies, and chemotherapeutic medications [82]. Conjugating targeted agents and active biomolecules via H-bonding, covalent bonding, and electrostatic interactions is a simple way to functionalize their surface. It is also simple to load numerous medications to increase therapeutic efficacy [83]. The ability of metallic nanoparticles to prolong the duration that drugs circulating in the blood, suppress or completely eradicate rapid renal drug excretion, and increase the water solubility of hydrophobic drug compounds is how they are obtained [84].

It is challenging issue to target the delivery of antineoplastic agents to cancer cells, so these drugs disseminate throughout the body, causing widespread toxicity, low patient acceptability, and sometimes even treatment termination [85]. Metallic nanoparticles are emerging as new carriers and contrast agents in cancer treatment [86]. Since metallic nanoparticles may be precisely regulated in form, size, charge, and surface modification, they are especially beneficial in cancer treatment [87]. Additionally, they are more readily absorbed by cells than non-metallic nanoparticles of the same size, which makes them advantageous for cancer treatment. For this aim, metallic nanoparticles have been used for imaging tumor cells using active and passive targeting so that metals have anticancer properties that are either surface-induced or natural [88].

Silver nanoparticles (AgNPs) are unique among metallic nanomaterials because of their wide variety of uses [89]. Several research groups have recently revealed that AgNPs can generate antitumoral effects in *in vitro* and *in vivo* tumor models, which could benefit various oncotherapy modalities and diagnostic tools [90], [91], [92], [93], [94]. This has led to an increased interest in AgNPs in nanomedicine [95]. AgNPs' toxicity is known to be dependent on the production of reactive oxygen species (ROS), which can occur directly (by electron donation to molecular oxygen, producing O_2) or indirectly (by interfering with mitochondrial structure and functions, leading to O_2^- leakage from the electron transport chain) [96]. The precise mechanisms by which AgNPs act against cancer cells are still not fully understood [97]. ROS, which includes superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (HO•), are byproducts of cellular oxygen metabolism. Since these compounds are crucial to signaling pathways, the cell's antioxidant pool keeps them at low levels under physiological settings. On the other hand, oxidative stress is linked to excessive ROS production [98]. AgNP exposure raises ROS levels, which causes cytotoxicity, lowers cell proliferation rates, damages macromolecules and organelles, and finally results in cell death [99].

Because of superior features of magnetic iron oxide nanoparticles (IONs) such as intrinsic magnetic qualities, or superparamagnetism, they are useful in various scientific domains, including electronics and the environment [100]. Moreover, IONs have much promise for use in therapeutic settings. When exposed to a different magnetic field, they can be used to create localized heat enhancement—a phenomenon known as magnetic hyperthermia application [101]. Because cancer cells cannot live in the 42–49°C temperature range, while healthy cells can, this feature is very effective in killing cancer cells [102]. Also, IONs are important nanocarriers as they can achieve high drug loading and targeting abilities [103], [104], [105]. It is well known that IONs can release drugs in a regulated way and can quickly transport drugs to a specific target spot when exposed to an external magnetic field [106], [107].

Gold nanoparticles (AuNPs), offer a versatile platform, especially for clinical and biomedical fields, due to their unique combination of physical, chemical, optical, and electrical capabilities [108]. Because AuNPs are potential nanocarriers for drug delivery because of their advantages including decreased side effects on healthy tissues, imaging or site targeting, and improved tissue permeability [109]. In addition, AuNPs are smaller than their biological targets; they can specifically interact and connect with biomolecules found inside cell organelles, in the cytoplasm, and on the surface of cells [110]. These

efficient nano-DDSs can transport various therapeutic agents, including peptides [111], proteins [112], genes [113], [114], [115], vaccines [116] and chemotherapy medicines [117].

F. GRAPHENES AND GRAPHENE OXIDES

Graphene, an allotrope of carbon making sp^2 bonds, is the thinnest material that forms a single-atom-thick planar surface within the honeycomb crystal lattice structure [118]. The graphite structure is formed by arranging carbon atoms in a hexagonal shape called a honeycomb in layers [119]. The graphite structure consisting of a single layer called "Graphene" [120]. Graphene is a two-dimensional material with unique structural, electronic, and optical properties [121]. Also, one of the most important properties of graphene is that it is the thinnest of all existing materials, being only one atom thick. It is a highly transparent material that absorbs very little light [122]. Graphene is in demand in many potential areas thanks to its features such as high specific surface area, electrical and thermal conductivity, high elastic modulus, and complex structure. Graphene-based materials, including graphene, graphene oxide (GO) and reduced graphene oxide (rGO) are classed based on their size, shape, and functional groups [123]. GO is utilized in various areas including biosensor technology insulation and environmental remediation [124], [125], [126].

The unique characteristics of graphene and graphene oxide, such as two-dimensional planar structure, large surface area, chemical and mechanical stability, exceptional conductivity, and favorable biocompatibility, have led to substantial research into these materials as some of the most promising biomaterials for biomedical applications [127]. Graphene's 2D structure and delocalized surface electrons can be used for efficient drug loading via hydrophobic interactions between hydrophobic drugs and aromatic groups of graphene without chemical modification of the drugs [128]. The large surface area of graphene enables covalent and non-covalent surface modification to achieve high-density biofunctionalization [129]. Graphene is a promising material that can be used as drug delivery systems for comparing against conventional agents. These characteristics lead to graphene-based nanocomposites considering as DDSs and to use for variety of treatments including delivery systems for antineoplastic agents such as cisplatin, doxorubicin, paclitaxel and so on [130].

G. CARBON NANOTUBES

One of the most prominent nanotechnology inventions in recent years is carbon nanotubes (CNTs). CNTs are rolls of graphene that have been sp2 hybridized and have diameters as small as one nanometer. The noteworthy features of CNTs are their high aspect ratio, low weight, superior conductivity qualities, and exceptional tensile strength, which qualify them for use as additions in a variety of products, such as metal substrates, ceramics, and polymers [131].

These structures are exceptional materials with many potential uses because of their strength, compact size, and extraordinary physical characteristics. These unique nanoscale-based features have remarkable mechanical and electrical features, unveiled by extensive global work in recent years [132]. Carbon nanotubes are now widely recognized as excellent model systems for researching the physics of one-dimensional solids and have great potential for building blocks in a wide range of useful nanoscale technologies [133]. Miniaturized electrical, mechanical, electromechanical, chemical, and scanning probe devices, as well as materials for macroscopic composites, have demonstrated the utility of nanotubes [134].

In addition to their electronic applications, CNTs have the potential to be applied in the pharmaceutical field as DDSs due to their specific surface area, biocompatibility, durability, and potential to carry large amounts of drugs and biomolecules [135]. These carbon nanoparticles can be engineered to help target or deliver drugs more effectively and develop novel therapeutic approaches, particularly for cancer treatment [130]. They can also be used to develop new diagnostic agents for malignancies and are anticipated to aid in combining therapies and molecular imaging for diagnosis [136].

Researchers have also recently discovered that CNT-based nanomaterials could be employed as carriers to control drug distribution, particularly with chemotherapeutic medications [137], [138], [139], [140], [141], [142], [143], [144], [145]. Multi-wall carbon nanotubes (MWCNT), utilized to target malignant cells, made up most of these carriers [146]. SWNT pharmacokinetics depends on several variables, including functional groups, pH, polymer molecular weight, drug loading techniques, and protonation [147]. They are also promising therapeutic bioimaging nanocarriers due to several other characteristics, such as photoacoustic, Raman scattering, and NIR fluorescence absorption [148]. The outcomes of studies conducted on animals and in laboratories for diagnosis and therapy have grown increasingly promising [149], [150]. The compilation of studies has brought to light the necessity of a thorough evaluation that covers CNT dosage, duration, induction technique, and other factors to create the most controlled environments possible for research involving humans and animals [151], [152], [153].

H. QUANTUM DOTS

Nanoparticles with zero dimensions are called quantum dots (QDs). Because all their dimensions are smaller than 100 nanometers, this short definition makes them known. Their sizes typically range from 2 to 15 nanometers [154]. The first characteristic of nanocrystal materials that can be distinguished is zero-dimensional (0D) materials. These materials are sometimes referred to as "QDs" because their electrons are primarily located in restricted areas and are confined in three dimensions, which makes them 0D structures [154]. They are also referred to as "artificial atoms" because of their distinct energy states [155].

The effectiveness of employing QDs in biological sensing, imaging, and detection has prompted researchers to advance this technology in translational and clinical medicine [156]. Since traceable drug delivery offers the potential to clarify the pharmacokinetics and pharmacodynamics of therapeutic candidates and provide the design guidelines for drug carrier engineering, it is one of the most significant new uses of QDs [157].

In biological domains, QDs-based nano-carriers for pharmaceuticals, can enhance the bioavailability of pharmaceuticals and enable therapeutic targeting [158], [159], [160], [161]. Furthermore, the implementation of a QD nano-carrier system for pharmaceuticals could lead to the achievement of early illness site detection, tracking, and targeted localized treatments such as cancer therapy, Alzheimer disease and cardiovascular diseases [162], [163], [164], [165], [166], [167], [168], [169]. Moreover, QD nano-carrier drug delivery systems can increase a medication's stability, prolong its half-life in vivo, improve targeted absorption, and optimize drug distribution and metabolism inside an organization [170], [171], [172], [173]. Thus, one of the main areas of interest in nanodrug research is the development of QD nano-carriers for pharmaceuticals [174], [175].

QDs are easily interchangeable with other inorganic (like gold) or organic (like condensed DNA) nanoparticle cores of interest because to their lower size, which makes them ideal for examining nanocarrier behavior and refining nanocarrier characteristics. In addition, QDs can be discreetly added to bigger DDSs as tracers to keep an eye on intracellular trafficking and biodistribution. Lastly, individual QDs released from bigger carriers can simulate the eventual removal of other nanoparticle components or the redistribution of free drug [176]. Furthermore, because QDs can function as the primary nanocarrier or fluorescent labels in a more intricate design, they make efficient candidates for theragnostic platforms [156].

III. CONCLUSION

Nanoparticulate systems have been utilized in various fields, including medical treatment, cosmetics, sunscreens, electronics, catalysis, and so on. Recently, nanopharmaceutics, which are nanoparticles that deliver therapeutic substances to organs, tissues, or cells, have emerged as a highly exciting field of study because they can change the pharmacokinetics, bioavailability, and biodistribution of therapeutic

agents. They can improve therapeutic efficacy and reduce the toxic effects of the drug molecules. Due to their size and surface modification ability, they can play significant roles in targeted drug delivery. Nanoparticulate systems for drug delivery have been investigated using a wide range of materials including natural and/or synthetic polymers, magnetic nanoparticles, dendrimers, lipid-based nanomaterials and so on. In addition, in near future, it is envisaged that they are not only spherical, but also produced in different shapes such as rods, discs, ellipses and stars, and that this shape difference may contribute to the delivery of the therapeutic substance to the desired organs and tissues. Moreover, nanoparticulate systems can be used in not only drug delivery but also diagnostics, tissue engineering, hyperthermia, biosensors, gene therapy, wound healing, dentistry, regenerative medicine, antimicrobial and antioxidant therapy, and bioimaging.

IV. REFERENCES

[1] K. Çetin, K. Şarkaya, and A. Denizli, "Clinical applications and future clinical trials of the drug delivery system," in *Nanotechnology for Drug Delivery and Pharmaceuticals*, R. P. Singh, J. Singh, K. R. Singh, and C. O. Adetunji, Eds., Elsevier, 2023, pp. 259–294. doi: 10.1016/B978-0-323-95325-2.00020-1.

[2] S. Logothetidis, "Nanotechnology: Principles and applications," *NanoScience and Technology*, vol. 59, pp. 1–22, 2012, doi: 10.1007/978-3-642-22227-6_1.

[3] F. Akbar, M. Kolahdouz, S. Larimian, B. Radfar, and H. H. Radamson, "Graphene synthesis, characterization and its applications in nanophotonics, nanoelectronics, and nanosensing," *Journal of Materials Science: Materials in Electronics*, vol. 26, no. 7, pp. 4347–4379, 2015, doi: 10.1007/S10854-015-2725-9.

[4] Ş. Çalık Bostancı, A. Boyraz, T. Şenel Zor, E. Zor, O. Aslan, and H. Bingöl, "Zenginleştirilmiş Öğrenme Ortamındaki Nanobilim ve Nanoteknoloji Eğitiminin Öğrencilerin Görüş ve Farkındalıklarına Etkisi," *Ahmet Keleşoğlu Eğitim Fakültesi Dergisi*, vol. 5, no. 3, pp. 1058–1086, 2023, doi: 10.38151/akef.2023.99.

[5] D. Frank *et al.*, "Overview of the role of nanotechnological innovations in the detection and treatment of solid tumors," *Int J Nanomedicine*, p. 589, 2014, doi: 10.2147/IJN.S50941.

[6] H. Yavuz, K. Çetin, S. Akgönüllü, D. Battal, and A. Denizli, "Therapeutic protein and drug imprinted nanostructures as controlled delivery tools," in *Design and Development of New Nanocarriers*, Alexandru Mihai Grumezescu, Ed., William Andrew Publishing, 2018, pp. 439–473. doi: 10.1016/B978-0-12-813627-0.00012-0.

[7] K. M. El-Say and H. S. El-Sawy, "Polymeric nanoparticles: Promising platform for drug delivery," *Int J Pharm*, vol. 528, no. 1–2, pp. 675–691, 2017, doi: 10.1016/J.IJPHARM.2017.06.052.

[8] T. Patel, J. Zhou, J. M. Piepmeier, and W. M. Saltzman, "Polymeric nanoparticles for drug delivery to the central nervous system," *Adv Drug Deliv Rev*, vol. 64, no. 7, pp. 701–705, 2012, doi: 10.1016/J.ADDR.2011.12.006.

[9] K. C. de Castro, J. M. Costa, and M. G. N. Campos, "Drug-loaded polymeric nanoparticles: a review," *Int J Polym Mater*, vol. 71, no. 1, pp. 1–13, 2022, doi: 10.1080/00914037.2020.1798436.

[10] B. Shaqour, A. Samaro, B. Verleije, K. Beyers, C. Vervaet, and P. Cos, "Production of Drug Delivery Systems Using Fused Filament Fabrication: A Systematic Review," *Pharmaceutics*, vol. 12, no. 6, p. 517, 2020, doi: 10.3390/PHARMACEUTICS12060517.

[11] F. Tao *et al.*, "Chitosan-based drug delivery systems: From synthesis strategy to osteomyelitis treatment – A review," *Carbohydr Polym*, vol. 251, p. 117063, 2021, doi: 10.1016/J.CARBPOL.2020.117063.

[12] E. Tamahkar, M. Bakhshpour, and A. Denizli, "Molecularly imprinted composite bacterial cellulose nanofibers for antibiotic release," *J Biomater Sci Polym Ed*, vol. 30, no. 6, pp. 450–461, 2019, doi: 10.1080/09205063.2019.1580665.

[13] H. Li *et al.*, "The protein corona and its effects on nanoparticle-based drug delivery systems," *Acta Biomater*, vol. 129, pp. 57–72, 2021, doi: 10.1016/J.ACTBIO.2021.05.019.

[14] K. Çetin, S. Aslıyüce, N. Idil, and A. Denizli, "Preparation of lysozyme loaded gelatin microcryogels and investigation of their antibacterial properties," *J Biomater Sci Polym Ed*, vol. 32, no. 2, pp. 189–204, 2021, doi: 10.1080/09205063.2020.1825303.

[15] Z. Zhang, S. Ai, Z. Yang, and X. Li, "Peptide-based supramolecular hydrogels for local drug delivery," *Adv Drug Deliv Rev*, vol. 174, pp. 482–503, 2021, doi: 10.1016/J.ADDR.2021.05.010.

[16] F. Mo, K. Jiang, D. Zhao, Y. Wang, J. Song, and W. Tan, "DNA hydrogel-based gene editing and drug delivery systems," *Adv Drug Deliv Rev*, vol. 168, pp. 79–98, 2021, doi: 10.1016/J.ADDR.2020.07.018.

[17] X. Li *et al.*, "Recent advances in targeted delivery of non-coding RNA-based therapeutics for atherosclerosis," *Molecular Therapy*, vol. 30, no. 10, pp. 3118–3132, 2022, doi: 10.1016/J.YMTHE.2022.07.018.

[18] S. Esthar *et al.*, "An anti-inflammatory controlled nano drug release and pH-responsive poly lactic acid appended magnetic nanosphere for drug delivery applications," *Mater Today Commun*, vol. 34, p. 105365, 2023, doi: 10.1016/J.MTCOMM.2023.105365.

[19] A. Behl, V. S. Parmar, S. Malhotra, and A. K. Chhillar, "Biodegradable diblock copolymeric PEG-PCL nanoparticles: Synthesis, characterization and applications as anticancer drug delivery agents," *Polymer (Guildf)*, vol. 207, p. 122901, 2020, doi: 10.1016/J.POLYMER.2020.122901.

[20] L. P. Jahromi, M. Ghazali, H. Ashrafi, and A. Azadi, "A comparison of models for the analysis of the kinetics of drug release from PLGA-based nanoparticles," *Heliyon*, p. e03451, 2017, doi: 10.1016/j.heliyon.2020.e03451.

[21] L. Shi *et al.*, "Effects of polyethylene glycol on the surface of nanoparticles for targeted drug delivery," *Nanoscale*, vol. 13, no. 24, pp. 10748–10764, 2021, doi: 10.1039/D1NR02065J.

[22] N. Mangiacotte, G. Prosperi-Porta, L. Liu, M. Dodd, and H. Sheardown, "Mucoadhesive Nanoparticles for Drug Delivery to the Anterior Eye," *Nanomaterials*, vol. 10, no. 7, p. 1400, Jul. 2020, doi: 10.3390/NANO10071400.

[23] K. Çetin and A. Denizli, “Polyethylenimine-functionalized microcryogels for controlled release of diclofenac sodium,” *React Funct Polym*, vol. 170, p. 105125, 2022, doi: 10.1016/J.REACTFUNCTPOLYM.2021.105125.

[24] M. Bakhshpour, H. Yavuz, and A. Denizli, “Controlled release of mitomycin C from PHEMAH–Cu(II) cryogel membranes,” *Artif Cells Nanomed Biotechnol*, vol. 46, no. sup1, pp. 946–954, 2018, doi: 10.1080/21691401.2018.1439840.

[25] J. Luo *et al.*, “Constructing a drug release model by central composite design to investigate the interaction between drugs and temperature-sensitive controlled release nanoparticles,” *Eur J Pharm Biopharm*, vol. 183, pp. 24–32, 2023, doi: 10.1016/J.EJPB.2022.12.009.

[26] D. D. Lasic and Y. Barenholz, “Liposomes: Past, Present, and Future,” *Handbook of Nonmedical Applications of Liposomes: From Gene Delivery and Diagnostics to Ecology*, pp. 299–316, 2019, doi: 10.1201/9780429291470-21.

[27] C. Has and P. Sunthar, “A comprehensive review on recent preparation techniques of liposomes,” *J Liposome Res*, vol. 30, no. 4, pp. 336–365, 2020, doi: 10.1080/08982104.2019.1668010.

[28] H. Nsairat *et al.*, “Liposome bilayer stability: emphasis on cholesterol and its alternatives,” *J Liposome Res*, 2023, doi: 10.1080/08982104.2023.2226216.

[29] S. Pande, “Liposomes for drug delivery: review of vesicular composition, factors affecting drug release and drug loading in liposomes,” *Artif Cells Nanomed Biotechnol*, vol. 51, no. 1, pp. 428–440, 2023, doi: 10.1080/21691401.2023.2247036.

[30] A. Gonzalez Gomez and Z. Hosseinidoust, “Liposomes for Antibiotic Encapsulation and Delivery,” *ACS Infect Dis*, vol. 6, no. 5, pp. 896–908, 2020, doi: 10.1021/ACSINFECDIS.9B00357

[31] P. Kumari, S. Kaur, S. Sharma, and H. K. Kashyap, “Impact of amphiphilic molecules on the structure and stability of homogeneous sphingomyelin bilayer: Insights from atomistic simulations,” *Journal of Chemical Physics*, vol. 148, no. 16, 2018, doi: 10.1063/1.5021310/196112.

[32] P. Kesharwani, K. Kumari, R. Gururani, S. Jain, and S. Sharma, “Approaches to Address PK-PD Challenges of Conventional Liposome Formulation with Special Reference to Cancer, Alzheimer’s, Diabetes, and Glaucoma: An Update on Modified Liposomal Drug Delivery System,” *Curr Drug Metab*, vol. 23, no. 9, pp. 678–692, 2022, doi: 10.2174/1389200223666220609141459.

[33] S. Maritim, P. Boulas, and Y. Lin, “Comprehensive analysis of liposome formulation parameters and their influence on encapsulation, stability and drug release in glibenclamide liposomes,” *Int J Pharm*, vol. 592, p. 120051, 2021, doi: 10.1016/J.IJPHARM.2020.120051.

[34] L. van der Koog, T. B. Gandek, and A. Nagelkerke, “Liposomes and Extracellular Vesicles as Drug Delivery Systems: A Comparison of Composition, Pharmacokinetics, and Functionalization,” *Adv Healthc Mater*, vol. 11, no. 5, p. 2100639, 2022, doi: 10.1002/ADHM.202100639.

[35] S. Amatya *et al.*, “Drug release testing methods of polymeric particulate drug formulations,” *J Pharm Investig*, vol. 43, no. 4, pp. 259–266, 2013, doi: 10.1007/S40005-013-0072-5/TABLES/2.

[36] S. Modi and B. D. Anderson, “Determination of drug release kinetics from nanoparticles: Overcoming pitfalls of the dynamic dialysis method,” *Mol Pharm*, vol. 10, no. 8, pp. 3076–3089, 2013, doi: 10.1021/MP400154A

[37] S. J. Wallace, J. Li, R. L. Nation, and B. J. Boyd, “Drug release from nanomedicines: Selection of appropriate encapsulation and release methodology,” *Drug Deliv Transl Res*, vol. 2, no. 4, pp. 284–292, 2012, doi: 10.1007/S13346-012-0064-4

[38] E. A. Grego *et al.*, “Polymeric Nanoparticle-Based Vaccine Adjuvants and Delivery Vehicles,” *Curr Top Microbiol Immunol*, vol. 433, pp. 29–76, 2021, doi: 10.1007/82_2020_226

[39] R. Amato *et al.*, “Liposome-Mediated Delivery Improves the Efficacy of Lisosan G against Retinopathy in Diabetic Mice,” *Cells*, vol. 12, no. 20, p. 2448, Oct. 2023, doi: 10.3390/CELLS12202448.

[40] A. Artzy-Schnirman *et al.*, “Advanced human-relevant in vitro pulmonary platforms for respiratory therapeutics,” *Adv Drug Deliv Rev*, vol. 176, p. 113901, 2021, doi: 10.1016/J.ADDR.2021.113901.

[41] Y. Yamada, Satrialdi, M. Hibino, D. Sasaki, J. Abe, and H. Harashima, “Power of mitochondrial drug delivery systems to produce innovative nanomedicines,” *Adv Drug Deliv Rev*, vol. 154–155, pp. 187–209, 2020, doi: 10.1016/J.ADDR.2020.09.010.

[42] K. Thapa Magar, G. F. Boafo, X. Li, Z. Chen, and W. He, “Liposome-based delivery of biological drugs,” *Chinese Chemical Letters*, vol. 33, no. 2, pp. 587–596, 2022, doi: 10.1016/J.CCLET.2021.08.020.

[43] S. Jain, S. V. Deore, R. Ghadi, D. Chaudhari, K. Kuche, and S. S. Katiyar, “Tumor microenvironment responsive VEGF-antibody functionalized pH sensitive liposomes of docetaxel for augmented breast cancer therapy,” *Mater Sci Eng C*, vol. 121, p. 111832, 2021, doi: 10.1016/J.MSEC.2020.111832.

[44] R. Swami *et al.*, “pH sensitive liposomes assisted specific and improved breast cancer therapy using co-delivery of SIRT1 shRNA and Docetaxel,” *Mater Sci Eng C*, vol. 120, p. 111664, 2021, doi: 10.1016/J.MSEC.2020.111664.

[45] S. Portilla, L. Fernández, D. Gutiérrez, A. Rodríguez, and P. García, “Encapsulation of the Antistaphylococcal Endolysin LysRODI in pH-Sensitive Liposomes,” *Antibiotics* vol. 9, no. 5, p. 242, 2020, doi: 10.3390/ANTIBIOTICS9050242.

[46] X. Ding *et al.*, “Designing Aptamer-Gold Nanoparticle-Loaded pH-Sensitive Liposomes Encapsulate Morin for Treating Cancer,” *Nanoscale Res Lett*, vol. 15, no. 1, pp. 1–17, 2020, doi: 10.1186/S11671-020-03297-X.

[47] Y. Il Park *et al.*, “pH-sensitive multi-drug liposomes targeting folate receptor β for efficient treatment of non-small cell lung cancer,” *J Control Release*, vol. 330, pp. 1–14, 2021, doi: 10.1016/J.JCONREL.2020.12.011.

[48] Y. Chen *et al.*, "Co-delivery of doxorubicin and epacadostat via heparin coated pH-sensitive liposomes to suppress the lung metastasis of melanoma," *Int J Pharm*, vol. 584, p. 119446, 2020, doi: 10.1016/J.IJPHARM.2020.119446.

[49] A. Ibrahim Bekraki, "Liposomes-and niosomes-based drug delivery systems for tuberculosis treatment," in *Nanotechnology Based Approaches for Tuberculosis Treatment*, P. Kesharwani, Ed., Elsevier, 2020, pp. 107–122. doi: 10.1016/B978-0-12-819811-7.00007-2.

[50] S. Khoee and M. Yaghoobian, "Niosomes: a novel approach in modern drug delivery systems," in Nanostructures for Drug Delivery, E. Andronescu and A. M. Grumezescu, Ed., Elsevier, 2017, pp. 207–237, doi: 10.1016/B978-0-323-46143-6.00006-3.

[51] E. Desmet, M. Van Gele, and J. Lambert, "Topically applied lipid- and surfactant-based nanoparticles in the treatment of skin disorders," *Expert Opin Drug Deliv*, vol. 14, no. 1, pp. 109–122, 2017, doi: 10.1080/17425247.2016.1206073.

[52] M. Ning, Y. Guo, H. Pan, X. Chen, and Z. Gu, "Preparation, in Vitro and in Vivo Evaluation of Liposomal/Niosomal Gel Delivery Systems for Clotrimazole," *Drug Dev Ind Pharm*, vol. 31, no. 4–5, pp. 375–383, 2005, doi: 10.1081/DDC-54315.

[53] G. Amoabediny *et al.*, "Overview of preparation methods of polymeric and lipid-based (niosome, solid lipid, liposome) nanoparticles: A comprehensive review," *Int J Polym Mater*, vol. 67, no. 6, pp. 383–400, 2018, doi: 10.1080/00914037.2017.1332623.

[54] J. Wen, M. Al Galloni, N. Yin, and A. Rashidinejad, "Liposomes and Niosomes," *Emulsion-based Systems for Delivery of Food Active Compounds: Formation, Application, Health and Safety*, pp. 263–292, 2018, doi: 10.1002/9781119247159.CH10.

[55] F. Sakar *et al.*, "Nano drug delivery systems and gamma radiation sterilization," *Pharm Dev Technol*, vol. 22, no. 6, pp. 775–784, 2017, doi: 10.3109/10837450.2016.1163393.

[56] M. Nasr, S. Mansour, N. D. Mortada, and A. A. Elshamy, "Vesicular aceclofenac systems: A comparative study between liposomes and niosomes," *J Microencapsul*, vol. 25, no. 7, pp. 499–512, 2008, doi: 10.1080/02652040802055411.

[57] S. J. Purohit, M. Tharmavaram, D. Rawtani, P. Prajapati, H. Pandya, and A. Dey, "Niosomes as cutting edge nanocarrier for controlled and targeted delivery of essential oils and biomolecules," *J Drug Deliv Sci Technol*, vol. 73, p. 103438, 2022, doi: 10.1016/J.JDDST.2022.103438.

[58] P. Bhardwaj, P. Tripathi, R. Gupta, and S. Pandey, "Niosomes: A review on niosomal research in the last decade," *J Drug Deliv Sci Technol*, vol. 56, p. 101581, 2020, doi: 10.1016/J.JDDST.2020.101581.

[59] G. P. Kumar and P. Rajeshwarrao, "Nonionic surfactant vesicular systems for effective drug delivery—an overview," *Acta Pharm Sin B*, vol. 1, no. 4, pp. 208–219, 2011, doi: 10.1016/J.APSB.2011.09.002.

[60] A. Z. M. Khalifa and B. K. Abdul Rasool, "Optimized Mucoadhesive Coated Niosomes as a Sustained Oral Delivery System of Famotidine," *AAPS PharmSciTech*, vol. 18, no. 8, pp. 3064–3075, 2017, doi: 10.1208/S12249-017-0780-7

[61] Z. Sezgin Bayindir, A. Beşikci, and N. Yüksel, "Paclitaxel-loaded niosomes for intravenous administration: pharmacokineticsand tissue distribution in rats," *Turk J Med Sci*, vol. 45, no. 6, pp. 1403–1412, 2015, doi: 10.3906/sag-1408-129.

[62] H. A. Saafan *et al.*, "Intratracheal Administration of Chloroquine-Loaded Niosomes Minimize Systemic Drug Exposure," *Pharmaceutics*, vol. 13, no. 10, p. 1677, Oct. 2021, doi: 10.3390/PHARMACEUTICS13101677.

[63] M. Dehghani *et al.*, "Triamcinolone-loaded self nano-emulsifying drug delivery systems for ocular use: An alternative to invasive ocular surgeries and injections," *Int J Pharm*, vol. 653, p. 123840, Mar. 2024, doi: 10.1016/J.IJPHARM.2024.123840.

[64] Y. T. H. Tran, G. N. Tran, A. L. Hoang, and G. T. T. Vu, "Niosomes loaded with diclofenac for transdermal administration: Physico-chemical characterization, ex vivo and in vivo skin permeation studies," *J Appl Pharm Sci*, vol. 10, no. 12, pp. 53–61, 2020, doi: 10.7324/JAPS.2020.101207.

[65] H. F. Salem, R. M. Kharshoum, H. A. Abou-Taleb, H. O. Farouk, and R. M. Zaki, "Fabrication and Appraisal of Simvastatin via Tailored Niosomal Nanovesicles for Transdermal Delivery Enhancement: In Vitro and In Vivo Assessment," *Pharmaceutics 2021, Vol. 13, Page 138*, vol. 13, no. 2, p. 138, 2021, doi: 10.3390/PHARMACEUTICS13020138.

[66] S. S. Pandey *et al.*, "Topical delivery of cyclosporine loaded tailored niosomal nanocarriers for improved skin penetration and deposition in psoriasis: Optimization, ex vivo and animal studies," *J Drug Deliv Sci Technol*, vol. 63, p. 102441, 2021, doi: 10.1016/J.JDDST.2021.102441.

[67] A. Shah, S. Boldhane, A. Pawar, and C. Bothiraja, "Advanced development of a non-ionic surfactant and cholesterol material based niosomal gel formulation for the topical delivery of anti-acne drugs," *Mater Adv*, vol. 1, no. 6, pp. 1763–1774, 2020, doi: 10.1039/D0MA00298D.

[68] K. Sridhar, B. S. Inbaraj, and B. H. Chen, "Recent Advances on Nanoparticle Based Strategies for Improving Carotenoid Stability and Biological Activity," *Antioxidants*, vol. 10, no. 5, p. 713, 2021, doi: 10.3390/ANTIOX10050713.

[69] H. A. Gad, R. S. Elezaby, M. Mansour, and R. M. Hathout, "Novel Approaches of Solid Lipid Nanoparticles as Drug Carrier," *Nanoengineering of Biomaterials: Drug Delivery & Biomedical Applications, 2 Volumes*, vol. 1–2, pp. 107–143, 2021, doi: 10.1002/9783527832095.CH5.

[70] J. Ye, Q. Wang, X. Zhou, and N. Zhang, "Injectable actarit-loaded solid lipid nanoparticles as passive targeting therapeutic agents for rheumatoid arthritis," *Int J Pharm*, vol. 352, no. 1–2, pp. 273–279, 2008, doi: 10.1016/J.IJPHARM.2007.10.014.

[71] N. Osman, N. Devnarain, C. A. Omolo, V. Fasiku, Y. Jaglal, and T. Govender, "Surface modification of nano-drug delivery systems for enhancing antibiotic delivery and activity," *Wiley Interdiscip Rev Nanomed Nanobiotechnol*, vol. 14, no. 1, p. e1758, Jan. 2022, doi: 10.1002/WNAN.1758.

[72] Y. Mirchandani, V. B. Patravale, and S. Brijesh, "Solid lipid nanoparticles for hydrophilic drugs," *J Control Release*, vol. 335, pp. 457–464, 2021, doi: 10.1016/J.JCONREL.2021.05.032.

[73] S. Bertoni, B. Albertini, J. Ronowicz-Pilarczyk, and N. Passerini, “Tailoring the release of drugs having different water solubility by hybrid polymer-lipid microparticles with a biphasic structure,” *Eur J Pharm Biopharm*, vol. 190, pp. 171–183, 2023, doi: 10.1016/J.EJPB.2023.07.017.

[74] N. K. Garg, B. Singh, R. K. Tyagi, G. Sharma, and O. P. Katare, “Effective transdermal delivery of methotrexate through nanostructured lipid carriers in an experimentally induced arthritis model,” *Colloids Surf B Biointerfaces*, vol. 147, pp. 17–24, 2016, doi: 10.1016/J.COLSURFB.2016.07.046.

[75] M. J. Ansari *et al.*, “Enhanced oral bioavailability of insulin-loaded solid lipid nanoparticles: pharmacokinetic bioavailability of insulin-loaded solid lipid nanoparticles in diabetic rats,” *Drug Deliv*, vol. 23, no. 6, pp. 1972–1979, 2016, doi: 10.3109/10717544.2015.1039666.

[76] R. Arora, S. S. Katiyar, V. Kushwah, and S. Jain, “Solid lipid nanoparticles and nanostructured lipid carrier-based nanotherapeutics in treatment of psoriasis: a comparative study,” *Expert Opin Drug Deliv*, vol. 14, no. 2, pp. 165–177, 2017, doi: 10.1080/17425247.2017.1264386.

[77] M. Chountoulesi and C. Demetzos, “Promising Nanotechnology Approaches in Treatment of Autoimmune Diseases of Central Nervous System,” *Brain Sciences*, vol. 10, no. 6, p. 338, 2020, doi: 10.3390/BRAINSCI10060338.

[78] A. Schröfel, G. Kratošová, I. Šafařík, M. Šafaříková, I. Raška, and L. M. Shor, “Applications of biosynthesized metallic nanoparticles – A review,” *Acta Biomater*, vol. 10, no. 10, pp. 4023–4042, 2014, doi: 10.1016/J.ACTBIO.2014.05.022.

[79] H. M. Yadav *et al.*, “Metal oxide-based composites: synthesis and characterization,” in *Advances in Metal Oxides and Their Composites for Emerging Applications*, S. D. Delekar, Ed., Elsevier, 2022, pp. 57–96. doi: 10.1016/B978-0-323-85705-5.00010-5.

[80] M. İ. Özgün, A. B. Batıbay, B. Ünal, Y. R. Eker, and A. Terlemez, “Investigation of the Use of TiO2 Obtained from Endodontic NiTi Files in Dye-Sensitized Solar Cells,” *Necmettin Erbakan University Journal of Science and Engineering*, vol. 5, no. 1, pp. 1–8, 2023, doi: 10.47112/neufmbd.2023.4.

[81] E. R. Cooper, “Nanoparticles: A personal experience for formulating poorly water soluble drugs,” *J Control Release*, vol. 141, no. 3, pp. 300–302, 2010, doi: 10.1016/J.JCONREL.2009.10.006.

[82] S. Vijayaram *et al.*, “Applications of Green Synthesized Metal Nanoparticles — a Review,” *Biological Trace Element Research 2023 202:1*, vol. 202, no. 1, pp. 360–386, 2023, doi: 10.1007/S12011-023-03645-9.

[83] K. Thanki, R. P. Gangwal, A. T. Sangamwar, and S. Jain, “Oral delivery of anticancer drugs: Challenges and opportunities,” *J Control Release*, vol. 170, no. 1, pp. 15–40, 2013, doi: 10.1016/J.JCONREL.2013.04.020.

[84] V. Chandrakala, V. Aruna, and G. Angajala, “Review on metal nanoparticles as nanocarriers: current challenges and perspectives in drug delivery systems,” *Emergent Materials 2021 5:6*, vol. 5, no. 6, pp. 1593–1615, 2022, doi: 10.1007/S42247-021-00335-X.

[85] M. D. K. Glasgow and M. B. Chougule, “Recent Developments in Active Tumor Targeted Multifunctional Nanoparticles for Combination Chemotherapy in Cancer Treatment and Imaging,” *J Biomed Nanotechnol*, vol. 11, no. 11, pp. 1859–18982015, doi: 10.1166/JBN.2015.2145.

[86] E. Alphandéry, “Natural Metallic Nanoparticles for Application in Nano-Oncology,” *Int J Mol Sci*, vol. 21, no. 12, p. 4412, 2020, doi: 10.3390/IJMS21124412.

[87] E. R. Evans, P. Bugga, V. Asthana, and R. Drezek, “Metallic nanoparticles for cancer immunotherapy,” *Materials Today*, vol. 21, no. 6, pp. 673–685, 2018, doi: 10.1016/J.MATTOD.2017.11.022.

[88] Neha Desai, M. Momin, T. Khan, S. Gharat, R. S. Ningthoujam, and A. Omri, “Metallic nanoparticles as drug delivery system for the treatment of cancer,” *Expert Opin Drug Deliv*, vol. 18, no. 9, pp. 1261–1290, 2021, doi: 10.1080/17425247.2021.1912008.

[89] X. F. Zhang, Z. G. Liu, W. Shen, and S. Gurunathan, “Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches,” *Int J Mol Sci 2016, Vol. 17, Page 1534*, vol. 17, no. 9, p. 1534, 2016, doi: 10.3390/IJMS17091534.

[90] S. Prakash, D. Nallathamby, X.-H. N. Xu, and P. D. Nallathamby, “Study of cytotoxic and therapeutic effects of stable and purified silver nanoparticles on tumor cells,” *Nanoscale*, vol. 2, no. 6, pp. 942–952, 2010, doi: 10.1039/C0NR00080A.

[91] S. Haque, C. C. Norbert, R. Acharyya, S. Mukherjee, M. Kathirvel, and C. R. Patra, “Biosynthesized silver nanoparticles for cancer therapy and in vivo bioimaging,” *Cancers (Basel)*, vol. 13, no. 23, p. 6114, 2021, doi: 10.3390/CANCERS13236114/S1.

[92] M. M. Rageh, R. H. El-Gebaly, and M. M. Afifi, “Antitumor activity of silver nanoparticles in Ehrlich carcinoma-bearing mice,” *Naunyn Schmiedebergs Arch Pharmacol*, vol. 391, no. 12, pp. 1421–1430, 2018, doi: 10.1007/S00210-018-1558-5/TABLES/1.

[93] T. Shi, X. Sun, and Q.-Y. He, “Cytotoxicity of Silver Nanoparticles Against Bacteria and Tumor Cells,” *Curr Protein Pept Sci*, vol. 18, no. 999, pp. 1–1, 2016, doi: 10.2174/1389203718666161108092149.

[94] M. Irulappan Sriram, S. Barath Mani Kanth, K. Kalishwaralal, S. Gurunathan, and M. Irulappan Sriram Selvaraj Barath Mani Kanth Kalimuthu Kalishwaralal Sangiliyandi gurunathan, “Antitumor activity of silver nanoparticles in Dalton’s lymphoma ascites tumor model,” *Int J Nanomedicine*, vol. 5, no. 1, pp. 753–762, 2010, doi: 10.2147/IJN.S11727.

[95] B. Chakraborty *et al.*, “Immunomodulatory properties of silver nanoparticles contribute to anticancer strategy for murine fibrosarcoma,” *Cell Mol Immunol*, vol. 13, no. 2, pp. 191–205, 2015, doi: 10.1038/cmi.2015.05.

[96] B. Lee, M. J. Lee, S. J. Yun, K. Kim, I. H. Choi, and S. Park, “Silver nanoparticles induce reactive oxygen species-mediated cell cycle delay and synergistic cytotoxicity with 3-bromopyruvate in Candida albicans, but not in Saccharomyces cerevisiae,” *Int J Nanomedicine*, vol. 14, p. 4801, 2019, doi: 10.2147/IJN.S205736.

[97] R. R. Miranda, I. Sampaio, and V. Zucolotto, “Exploring silver nanoparticles for cancer therapy and diagnosis,” *Colloids Surf B Biointerfaces*, vol. 210, p. 112254, 2022, doi: 10.1016/J.COLSURFB.2021.112254.

[98] A. Fehaid and A. Taniguchi, “Silver nanoparticles reduce the apoptosis induced by tumor necrosis factor-α,” *Sci Technol Adv Mater*, vol. 19, no. 1, pp. 526–534, 2018, doi: 10.1080/14686996.2018.1487761.

[99] M. R. Garcia Garcia *et al.*, “Silver nanoparticles induce a non-immunogenic tumor cell death,” *J Immunotoxicol*, vol. 20, no. 1, 2023, doi: 10.1080/1547691X.2023.2175078.

[100] N. Y. Elamin, A. Modwi, W. Abd El-Fattah, and A. Rajeh, “Synthesis and structural of Fe3O4 magnetic nanoparticles and its effect on the structural optical, and magnetic properties of novel Poly(methyl methacrylate)/ Polyaniline composite for electromagnetic and optical applications,” *Opt Mater (Amst)*, vol. 135, p. 113323, Jan. 2023, doi: 10.1016/J.OPTMAT.2022.113323.

[101] T. Vangijzegem, D. Stanicki, and S. Laurent, “Magnetic iron oxide nanoparticles for drug delivery: applications and characteristics,” *Expert Opin Drug Deliv*, vol. 16, no. 1, pp. 69–78, Jan. 2019, doi: 10.1080/17425247.2019.1554647.

[102] H. N. Pham *et al.*, “Magnetic inductive heating of organs of mouse models treated by copolymer coated Fe3O4 nanoparticles*,” *Advances in Natural Sciences: Nanoscience and Nanotechnology*, vol. 8, no. 2, p. 025013, 2017, doi: 10.1088/2043-6254/AA5E23.

[103] S. Ayyanaar *et al.*, “ROS-responsive chitosan coated magnetic iron oxide nanoparticles as potential vehicles for targeted drug delivery in cancer therapy,” *Int J Nanomedicine*, vol. 15, pp. 3333–3346, 2020, doi: 10.2147/IJN.S249240.

[104] S. O. Aisida, P. A. Akpa, I. Ahmad, T. kai Zhao, M. Maaza, and F. I. Ezema, “Bio-inspired encapsulation and functionalization of iron oxide nanoparticles for biomedical applications,” *Eur Polym J*, vol. 122, p. 109371, 2020, doi: 10.1016/J.EURPOLYMJ.2019.109371.

[105] M. Suciu *et al.*, “Applications of superparamagnetic iron oxide nanoparticles in drug and therapeutic delivery, and biotechnological advancements,” *Beilstein J Nanotechnol 11:94*, vol. 11, no. 1, pp. 1092–1109, 2020, doi: 10.3762/BJNANO.11.94.

[106] S. Ayyanaar *et al.*, “Iron oxide nanoparticle core-shell magnetic microspheres: Applications toward targeted drug delivery,” *Nanomedicine*, vol. 24, p. 102134, 2020, doi: 10.1016/J.NANO.2019.102134.

[107] K. Çetin, F. Denizli, H. Yavuz, D. Türkmen, and A. Denizli, “Magnetic Nanoparticles and Their Biomedical Applications,” *Hacettepe J Biol Chem*, pp. 143–152, 2019, doi: 10.15671/hjbc.622644.

[108] E. C. Dreaden, L. A. Austin, M. A. MacKey, and M. A. El-Sayed, “Size matters: gold nanoparticles in targeted cancer drug delivery,” *http://dx.doi.org/10.4155/tde.12.21*, vol. 3, no. 4, pp. 457–478, 2012, doi: 10.4155/TDE.12.21.

[109] O. Veiseh *et al.*, “Inhibition of Tumor-Cell Invasion with Chlorotoxin-Bound Superparamagnetic Nanoparticles,” *Small*, vol. 5, no. 2, pp. 256–264, 2009, doi: 10.1002/SMLL.200800646.

[110] X. Zhang, "Gold Nanoparticles: Recent Advances in the Biomedical Applications," *Cell Biochem Biophys*, vol. 72, no. 3, pp. 771–775, 2015, doi: 10.1007/S12013-015-0529-4/FIGURES/2.

[111] K. Hori *et al.*, "Intracellular delivery and photothermal therapeutic effects of polyhistidine peptide-modified gold nanoparticles," *J Biotechnol*, vol. 354, pp. 34–44, 2022, doi: 10.1016/J.JBIOTEC.2022.06.006.

[112] S. Zhang and Y. Cheng, "Boronic acid-engineered gold nanoparticles for cytosolic protein delivery," *Biomater Sci*, vol. 8, no. 13, pp. 3741–3750, 2020, doi: 10.1039/D0BM00679C.

[113] S. Pouya, M. Kazemi, S. Pouya, A. Dehshahri, and Z. Sobhani, "Evaluation of CTAB coated gold nanoparticles as a potential carrier for gene delivery," *Trends in Pharmaceutical Sciences*, vol. 8, no. 3, pp. 147–154, 2022, doi: 10.30476/TIPS.2022.95505.1146.

[114] X. Xu, Y. Liu, Y. Yang, J. Wu, M. Cao, and L. Sun, "One-pot synthesis of functional peptide-modified gold nanoparticles for gene delivery," *Colloids Surf A Physicochem Eng Asp*, vol. 640, p. 128491, 2022, doi: 10.1016/J.COLSURFA.2022.128491.

[115] L. Bai, J. Zhao, M. Wang, Y. Feng, and J. Ding, "Matrix-Metalloproteinase-Responsive Gene Delivery Surface for Enhanced in Situ Endothelialization," *ACS Appl Mater Interfaces*, vol. 12, no. 36, pp. 40121–40132, 2020, doi: 10.1021/ACSAMI.0C11971

[116] D. Zhang *et al.*, "HSA-templated self-generation of gold nanoparticles for tumor vaccine delivery and combinational therapy," *J Mater Chem B*, vol. 10, no. 42, pp. 8750–8759, 2022, doi: 10.1039/D2TB01483A.

[117] S. Thambiraj, S. Hema, and D. Ravi Shankaran, "Functionalized gold nanoparticles for drug delivery applications," *Mater Today Proc*, vol. 5, no. 8, pp. 16763–16773, 2018, doi: 10.1016/J.MATPR.2018.06.030.

[118] N. P. Singh, V. K. Gupta, and A. P. Singh, "Graphene and carbon nanotube reinforced epoxy nanocomposites: A review," *Polymer (Guildf)*, vol. 180, p. 121724, 2019, doi: 10.1016/J.POLYMER.2019.121724.

[119] T. A. Land, T. Michely, R. J. Behm, J. C. Hemminger, and G. Comsa, "STM investigation of single layer graphite structures produced on Pt(111) by hydrocarbon decomposition," *Surf Sci*, vol. 264, no. 3, pp. 261–270, 1992, doi: 10.1016/0039-6028(92)90183-7.

[120] M. H. Islam *et al.*, "Graphene and CNT-Based Smart Fiber-Reinforced Composites: A Review," *Adv Funct Mater*, vol. 32, no. 40, p. 2205723, 2022, doi: 10.1002/ADFM.202205723.

[121] F. Lahourpour, A. Boochani, S. S. Parhizgar, and S. M. Elahi, "Structural, electronic and optical properties of graphene-like nano-layers MoX2(X:S,Se,Te): DFT study," *J Theor Appl Phys*, vol. 13, no. 3, pp. 191–201, 2019, doi: 10.1007/S40094-019-0333-4.

[122] H. Chang and H. Wu, "Graphene-Based Nanomaterials: Synthesis, Properties, and Optical and Optoelectronic Applications," *Adv Funct Mater*, vol. 23, no. 16, pp. 1984–1997, 2013, doi: 10.1002/ADFM.201202460.

[123] D. Maiti, X. Tong, X. Mou, and K. Yang, "Carbon-Based Nanomaterials for Biomedical Applications: A Recent Study," *Front Pharmacol*, vol. 9, p. 430833, 2019, doi: 10.3389/FPHAR.2018.01401/BIBTEX.

[124] N. F. Chiu, T. Y. Huang, H. C. Lai, and K. C. Liu, "Graphene oxide-based SPR biosensor chip for immunoassay applications," *Nanoscale Res Lett*, vol. 9, no. 1, p. 445, 2014, doi: 10.1186/1556-276X-9-445.

[125] X. Huang, F. Liu, P. Jiang, and T. Tanaka, "Is graphene oxide an insulating material?," *Proceedings of IEEE International Conference on Solid Dielectrics, ICSD*, pp. 904–907, 2013, doi: 10.1109/ICSD.2013.6619690.

[126] İ. Akın, E. Zor, and H. Bingöl, "GO@Fe3O4 Katkılı Polimerik Kompozit Membranların Hazırlanması ve Karakterizasyonu," *Necmettin Erbakan Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, vol. 5, no. 2, pp. 38–52, 2023, doi: 10.47112/neufmbd.2023.8.

[127] N. Rao, R. Singh, and L. Bashambu, "Carbon-based nanomaterials: Synthesis and prospective applications," *Mater Today Proc*, vol. 44, pp. 608–614, 2021, doi: 10.1016/J.MATPR.2020.10.593.

[128] S. Zheng, J. Xiong, L. Wang, D. Zhai, Y. Xu, and F. Lin, "e-Graphene: A Computational Platform for the Prediction of Graphene-Based Drug Delivery System by Quantum Genetic Algorithm and Cascade Protocol," *Front Chem*, vol. 9, p. 664355, 2021, doi: 10.3389/FCHEM.2021.664355/BIBTEX.

[129] Z. Guo *et al.*, "Surface Functionalization of Graphene-Based Materials: Biological Behavior, Toxicology, and Safe-By-Design Aspects," *Adv Biol*, vol. 5, no. 9, p. 2100637, 2021, doi: 10.1002/ADBI.202100637.

[130] J. Jampilek and K. Kralova, "Advances in Drug Delivery Nanosystems Using Graphene-Based Materials and Carbon Nanotubes," *Materials*, vol. 14, no. 5, p. 1059, 2021, doi: 10.3390/MA14051059.

[131] R. Jha, A. Singh, P. K. Sharma, and N. K. Fuloria, "Smart carbon nanotubes for drug delivery system: A comprehensive study," *J Drug Deliv Sci Technol*, vol. 58, p. 101811, 2020, doi: 10.1016/J.JDDST.2020.101811.

[132] A. T. Lawal, "Recent developments in electrochemical sensors based on graphene for bioanalytical applications," *Sens Biosensing Res*, vol. 41, p. 100571, 2023, doi: 10.1016/J.SBSR.2023.100571.

[133] X. Zhang *et al.*, "Understanding the Mechanical and Conductive Properties of Carbon Nanotube Fibers for Smart Electronics," *Adv Mater*, vol. 32, no. 5, p. 1902028, 2020, doi: 10.1002/ADMA.201902028.

[134] H. Dai, "Carbon nanotubes: opportunities and challenges," *Surf Sci*, vol. 500, no. 1–3, pp. 218–241, 2002, doi: 10.1016/S0039-6028(01)01558-8.

[135] A. V. V. V. Ravi Kiran, G. Kusuma Kumari, and P. T. Krishnamurthy, "Carbon nanotubes in drug delivery: Focus on anticancer therapies," *J Drug Deliv Sci Technol*, vol. 59, p. 101892, 2020, doi: 10.1016/J.JDDST.2020.101892.

[136] M. Barani, M. Khatami, B. Behnam, R. Rajendram, P. Kesharwani, and A. Sahebkar, "Aptamer-conjugated carbon nanotubes or graphene for targeted cancer therapy and diagnosis," *Aptamers Engineered Nanocarriers for Cancer Therapy*, pp. 277–294, 2023, doi: 10.1016/B978-0-323-85881-6.00018-X.

[137] L. Meng, X. Zhang, Q. Lu, Z. Fei, and P. J. Dyson, "Single walled carbon nanotubes as drug delivery vehicles: Targeting doxorubicin to tumors," *Biomaterials*, vol. 33, no. 6, pp. 1689–1698, 2012, doi: 10.1016/J.BIOMATERIALS.2011.11.004.

[138] R. Chadar, O. Afzal, S. M. Alqahtani, and P. Kesharwani, "Carbon nanotubes as an emerging nanocarrier for the delivery of doxorubicin for improved chemotherapy," *Colloids Surf B Biointerfaces*, vol. 208, p. 112044, 2021, doi: 10.1016/J.COLSURFB.2021.112044.

[139] M. Zarghami Dehaghani *et al.*, "Theoretical Encapsulation of Fluorouracil (5-FU) Anti-Cancer Chemotherapy Drug into Carbon Nanotubes (CNT) and Boron Nitride Nanotubes (BNNT)," *Molecules*, vol. 26, no. 16, p. 4920, 2021, doi: 10.3390/MOLECULES26164920.

[140] F. F. Contreras-Torres, D. Salas-Treviño, A. Soto-Domínguez, and G. De Jesús García-Rivas, "Carbon Nanotubes in Tumor-Targeted Chemotherapeutic Formulations: A Review of Opportunities and Challenges," *ACS Appl Nano Mater*, vol. 5, no. 7, pp. 8649–8679, 2022, doi: 10.1021/ACSANM.2C01118.

[141] S. Eskandari, A. Barzegar, and K. Mahnam, "Absorption of daunorubicin and etoposide drugs by hydroxylated and carboxylated carbon nanotube for drug delivery: theoretical and experimental studies," *J Biomol Struct Dyn*, vol. 40, no. 20, pp. 10057–10064, 2022, doi: 10.1080/07391102.2021.1938232.

[142] M. Dahri, H. Akbarialiabad, A. M. Jahromi, and R. Maleki, "Loading and release of cancer chemotherapy drugs utilizing simultaneous temperature and pH-responsive nanohybrid," *BMC Pharmacol Toxicol*, vol. 22, no. 1, pp. 1–10, 2021, doi: 10.1186/S40360-021-00508-8.

[143] S. Karimzadeh, B. Safaei, and T. C. Jen, "Theorical investigation of adsorption mechanism of doxorubicin anticancer drug on the pristine and functionalized single-walled carbon nanotube surface as a drug delivery vehicle: A DFT study," *J Mol Liq*, vol. 322, p. 114890, 2021, doi: 10.1016/J.MOLLIQ.2020.114890.

[144] H. Zare *et al.*, "Carbon nanotubes: Smart drug/gene delivery carriers," *Int J Nanomedicine*, vol. 16, pp. 1681–1706, 2021, doi: 10.2147/IJN.S299448.

[145] Z. Wang, J. Tao, J. Chen, and Q. Liu, "Carbon Nanotubes Enhance the Chemotherapy Sensitivity of Tumors with Multidrug Resistance," *Lett Drug Des Discov*, vol. 17, no. 4, pp. 366–378, 2019, doi: 10.2174/1570180816666190405110858.

[146] S. K. Debnath and R. Srivastava, "Drug Delivery With Carbon-Based Nanomaterials as Versatile Nanocarriers: Progress and Prospects," *Front Nanotechnol*, vol. 3, p. 644564, 2021, doi: 10.3389/FNANO.2021.644564.

[147] A. Khoshoei, E. Ghasemy, F. Poustchi, M. A. Shahbazi, and R. Maleki, "Engineering the pH-Sensitivity of the Graphene and Carbon Nanotube Based Nanomedicines in Smart Cancer Therapy by Grafting Trimetyl Chitosan," *Pharm Res*, vol. 37, no. 8, pp. 1–13, 2020, doi: 10.1007/S11095-020-02881-1.

[148] W. Gao *et al.*, "3D CNT/MXene microspheres for combined photothermal/photodynamic/chemo for cancer treatment," *Front Bioeng Biotechnol*, vol. 10, p. 996177, 2022, doi: 10.3389/FBIOE.2022.996177.

[149] K. de Almeida Barcelos, J. Garg, D. C. Ferreira Soares, A. L. B. de Barros, Y. Zhao, and L. Alisaraie, "Recent advances in the applications of CNT-based nanomaterials in pharmaceutical nanotechnology and biomedical engineering," *J Drug Deliv Sci Technol*, vol. 87, p. 104834, 2023, doi: 10.1016/J.JDDST.2023.104834.

[150] M. Das *et al.*, "Carbon nanotube embedded cyclodextrin polymer derived injectable nanocarrier: A multiple faceted platform for stimulation of multi-drug resistance reversal," *Carbohydr Polym*, vol. 247, p. 116751, 2020, doi: 10.1016/J.CARBPOL.2020.116751.

[151] L. Paseta *et al.*, "Functionalized graphene-based polyamide thin film nanocomposite membranes for organic solvent nanofiltration," *Sep Purif Technol*, vol. 247, p. 116995, 2020, doi: 10.1016/J.SEPPUR.2020.116995.

[152] W. Chen *et al.*, "Construction of Aptamer-siRNA Chimera/PEI/5-FU/Carbon Nanotube/Collagen Membranes for the Treatment of Peritoneal Dissemination of Drug-Resistant Gastric Cancer," *Adv Healthc Mater*, vol. 9, no. 21, p. 2001153, 2020, doi: 10.1002/ADHM.202001153.

[153] A. Yaghoubi and A. Ramazani, "Anticancer DOX delivery system based on CNTs: Functionalization, targeting and novel technologies," *J Control Release*, vol. 327, pp. 198–224, Nov. 2020, doi: 10.1016/J.JCONREL.2020.08.001.

[154] W. A. A. Mohamed *et al.*, "Quantum dots synthetization and future prospect applications," *Nanotechnol Rev*, vol. 10, no. 1, pp. 1926–1940, 2021, doi: 10.1515/NTREV-2021-0118.

[155] M. Çadırcı, K. Şarkaya, and A. Allı, "Dielectric properties of CdSe quantum dots-loaded cryogel for potential future electronic applications," *Mater Sci Semicond Process*, vol. 119, p. 105269, 2020, doi: 10.1016/J.MSSP.2020.105269.

[156] C. T. Matea *et al.*, "Quantum dots in imaging, drug delivery and sensor applications," *Int J Nanomedicine*, vol. 12, pp. 5421–5431, 2017, doi: 10.2147/IJN.S138624.

[157] T. Sahu, Y. K. Ratre, S. Chauhan, L. V. K. S. Bhaskar, M. P. Nair, and H. K. Verma, "Nanotechnology based drug delivery system: Current strategies and emerging therapeutic potential for medical science," *J Drug Deliv Sci Technol*, vol. 63, p. 102487, 2021, doi: 10.1016/J.JDDST.2021.102487.

[158] A. K. Babu *et al.*, "An overview of polymer surface coated synthetic quantum dots as therapeutics and sensors applications," *Prog Biophys Mol Biol*, vol. 184, pp. 1–12, 2023, doi: 10.1016/J.PBIOMOLBIO.2023.08.004.

[159] P. Sharma, V. Jain, and M. Tailang, "Advancement of Nanocarrier-Based Engineering for Specific Drug Delivery for Cancer Therapy," In Targeted Cancer Therapy in Biomedical Engineering Singapore: Springer Nature Singapore, pp. 465–486, 2023, doi: 10.1007/978-981-19-9786-0_13.

[160] P. K. Singh, S. Singh, K. Sachan, V. Verma, and S. Garg, "Recent Development and Advancement in Quantum Dots in Pharmaceutical and Biomedical Fields for the Delivery of

Drugs," *Curr Nanosci*, vol. 20, no. 4, pp. 425–435, 2023, doi: 10.2174/1573413719666230517111856.

[161] S. Khizar *et al.*, "Nanocarriers based novel and effective drug delivery system," *Int J Pharm*, vol. 632, p. 122570, 2023, doi: 10.1016/J.IJPHARM.2022.122570.

[162] U. Badıllı, F. Mollarasouli, N. K. Bakirhan, Y. Ozkan, and S. A. Ozkan, "Role of quantum dots in pharmaceutical and biomedical analysis, and its application in drug delivery," *TrAC Trends in Analytical Chemistry*, vol. 131, p. 116013, 2020, doi: 10.1016/J.TRAC.2020.116013.

[163] Y. Deng *et al.*, "Application of the Nano-Drug Delivery System in Treatment of Cardiovascular Diseases," *Front Bioeng Biotechnol*, vol. 7, p. 513812, 2020, doi: 10.3389/FBIOE.2019.00489/BIBTEX.

[164] M. Sohail *et al.*, "Nanocarrier-based Drug Delivery System for Cancer Therapeutics: A Review of the Last Decade," *Curr Med Chem*, vol. 28, no. 19, pp. 3753–3772, 2020, doi: 10.2174/0929867327666201005111722.

[165] A. A. H. Abdellatif *et al.*, "Nano-scale delivery: A comprehensive review of nano-structured devices, preparative techniques, site-specificity designs, biomedical applications, commercial products, and references to safety, cellular uptake, and organ toxicity," *Nanotechnol Rev*, vol. 10, no. 1, pp. 1493–1559, 2021, doi: 10.1515/NTREV-2021-0096

[166] M. Pourmadadi *et al.*, "Letrozole-Loaded Nano-formulations as a Drug Delivery System for Cancer Therapy: Recent Developments," *BioNanoScience 2023 13:4*, vol. 13, no. 4, pp. 1593–1608, 2023, doi: 10.1007/S12668-023-01196-W.

[167] M. D. Villalva, V. Agarwal, M. Ulanova, P. S. Sachdev, and N. Braidy, "Quantum dots as a theranostic approach in Alzheimer's disease: a systematic review," *Nanomedicin*e, vol. 16, no. 18, pp. 1595–1611, Jun. 2021, doi: 10.2217/NNM-2021-0104.

[168] X. Lu, X. Hou, H. Tang, X. Yi, and J. Wang, "A High-Quality CdSe/CdS/ZnS Quantum-Dot-Based FRET Aptasensor for the Simultaneous Detection of Two Different Alzheimer's Disease Core Biomarkers," *Nanomaterials*, vol. 12, no. 22, p. 4031, 2022, doi: 10.3390/NANO12224031.

[169] E. Morales-Narváez, H. Montón, A. Fomicheva, and A. Merkoçi, "Signal enhancement in antibody microarrays using quantum dots nanocrystals: Application to potential Alzheimer's disease biomarker screening," *Anal Chem*, vol. 84, no. 15, pp. 6821–6827, 2012, doi: 10.1021/AC301369E.

[170] S. Yasamineh *et al.*, "A state-of-the-art review on the recent advances of niosomes as a targeted drug delivery system," *Int J Pharm*, vol. 624, p. 121878, Aug. 2022, doi: 10.1016/J.IJPHARM.2022.121878.

[171] A. Kumar *et al.*, "Current and Future Nano-Carrier-Based Approaches in the Treatment of Alzheimer's Disease," *Brain Sciences*, vol. 13, no. 2, p. 213, 2023, doi: 10.3390/BRAINSCI13020213.

[172] A. A. Khafoor, A. S. Karim, and S. M. Sajadi, "Recent progress in synthesis of nano based liposomal drug delivery systems: A glance to their medicinal applications," *Results in Surfaces and Interfaces*, vol. 11, p. 100124, 2023, doi: 10.1016/J.RSURFI.2023.100124.

[173] S. S. Qi, J. H. Sun, H. H. Yu, and S. Q. Yu, “Co-delivery nanoparticles of anti-cancer drugs for improving chemotherapy efficacy,” *Drug Deliv*, vol. 24, no. 1, pp. 1909–1926, 2017, doi: 10.1080/10717544.2017.1410256.

[174] M. X. Zhao and B. J. Zhu, “The Research and Applications of Quantum Dots as Nano-Carriers for Targeted Drug Delivery and Cancer Therapy,” *Nanoscale Res Lett*, vol. 11, no. 1, pp. 1–9, 2016, doi: 10.1186/S11671-016-1394-9/FIGURES/8.

[175] M. A. Jahangir *et al.*, “Quantum Dots: Next Generation of Smart Nano-Systems,” *Pharm Nanotechnol*, vol. 7, no. 3, pp. 234–245, 2019, doi: 10.2174/2211738507666190429113906.

[176] C. E. Probst, P. Zrazhevskiy, V. Bagalkot, and X. Gao, “Quantum dots as a platform for nanoparticle drug delivery vehicle design,” *Adv Drug Deliv Rev*, vol. 65, no. 5. pp. 703–718, 2013. doi: 10.1016/j.addr.2012.09.036.