REVIEW ARTICLE

Clinical Application of Iron Oxide Nanoparticles in Dentistry: A Review

Munadle R. Hadi[1], Karar Najeh[1], Abdulsahib S. Jubran[1], Ibrahim J. Sahib[1], Haneen T. Ali[2]

[1]*College of Dentistry, University of Alkafeel, Najaf, Iraq*
[2]*Imam Ja'afar Al-sadiq University, Medical Laboratory Techniques, Najaf, Iraq*

Received: 24th August, 2021; Revised: 22nd September, 2021; Accepted: 28th November, 2021; Available Online: 25th December, 2021

ABSTRACT

Biotechnology, such as its application in medication, is commonly used during our everyday lives. Implementing nanomaterials (NMs), atoms, binding energies, and compounds existing within different compounds are easy to analyze and modify. Nanotechnology is being used as nano dentistry throughout the dental field. The chemical, physical and biological dimensions of iron oxide nanoparticles are taken as selecting a nanoparticle to be used in nano dentistry. To build the functional organizational structure, different atoms or molecules are also inserted. In dentistry advances or evaluation, iron oxide nanoparticles (IONPs) have been used. Including dental disease prevention medications, prostheses, and that for teeth implantation, iron oxide nanoparticles have been used. Also, iron oxide nanoparticles supply dental fluids or medications, avoid, and cure some dental problems (oral cancer), and sustain medical care to a significant level. Throughout the dental field, the whole review summarizes the use of iron oxide nanoparticles.

Keywords: Dental field, Dentistry, Iron oxide, Nanoparticle, Nanotechnology.

International Journal of Drug Delivery Technology (2021); DOI: 10.25258/ijddt.11.4.66

How to cite this article: Hadi MR, Najeh K, Jubran AS, Sahib IJ, Ali HT. Clinical Application of Iron Oxide Nanoparticles in Dentistry: A Review. International Journal of Drug Delivery Technology. 2021;11(4):1501-1506.

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Nanotechnology is a technique that deals with nanometer-sized structures and the particles are called nanoparticles (NPs).[1] Within the oral cavity, teeth are present and contain different sections, such as dentin, enamel, cement, pulp, and periodontal ligament. To make it easier to swallow and digest, the purpose of the teeth is to cut and crush the food.[2] Within the oral cavity, teeth are present and contain different sections, such as dentin, enamel, cement, pulp, and periodontal ligament. To make it easier to swallow and digest, the purpose of the teeth is to cut and crush the food.[3] For decades, the utilization of IONPs in oral consideration has been perceived as one of the vital segments of dental blends utilized for tooth reclamation and accomplished overall spread in the nineteenth century. Since 1930, its use in amalgams has been limited as they have been increasingly replaced by esthetic polymer-based resins.[2,4] Since nanomaterials has advanced, the impressive antibacterial activities of IONPs based nanosized formulas against microorganisms such as microbes, viruses, and fungi have been demonstrated.[5]

Chemical treatments are used to hold the teeth in the oral area. For filling the teeth, combination with solid mechanical properties is utilized. The combination system is utilized to solidify crowns and extensions.[1-6] With a polymerization light positioned into the oral hole, the sealing was fully hardened. Ionomers of glass are being used to temporarily fill deciduous teeth. This offers a good capacity for resistance and firmly seals crowns and bridges.[7]

Dental caries, periodontal infections, teeth irritation, bad breath, and oral precancerous and cancerous symptoms may also be caused by damaged dental tissues. Therapeutic interventions and the use of biocompatible synthetic products can be used to treat any of the above complications.[8]

Nanomedicines used as dental materials hae a number of physicochemical and biological characteristics. that makes them superior to more traditional dental treatments in terms of overcoming side effects.[9] Various types of nanomaterials have been shown to imitate host tissue features in studies[10,11] though there is no awareness of such features within dental populations. IONPs is a best choice for prosthesis because it is innocuous, exact, and unbending.[12] Earthenware production are being utilized in stable prosthetics (crowns and extensions). Steel in adaptable prosthetics is utilized for edges and catches.[8] The "carbamide peroxide" gels and hydrogen peroxide compounds are utilized to brighten the yellow-shaded tooth. Hg substitutes transfers that are heterogeneous and homogeneous. While these techniques are being used in the dentistry industry, they also have some drawbacks.[13] The biggest fault of amalgam, for instance, is that it includes mercury that is toxic to our bodies. Composite fillings are cold-hypersensitive.[14]

**Author for Correspondence: abdalsahebsaad@alkafeel.edu.iq*

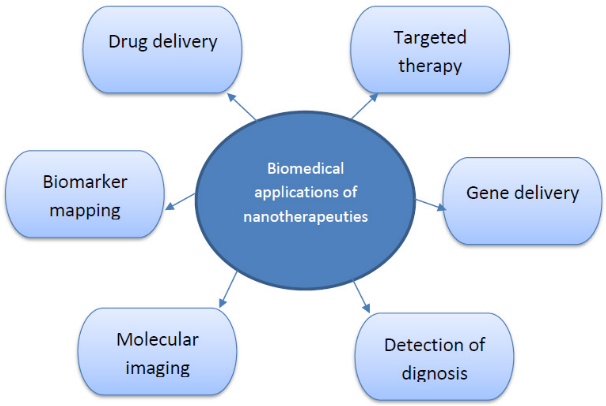

Figure 1: Schematic illustrated clinical application of NPs in dentistry

Ceramics in nature often can crack and be extremely difficult.[15]

In dentistry, nanoparticles are incorporated to take these drawbacks into account.[8,15] In contrast to maintaining and enhancing dental and oral hygiene, dental nanomaterials are specially manufactured products engineered for use in the diagnosis of oral and dental disease care and prevention. NMs are also used for prosthesis and teeth fertilization, delivery of oral medications, and treating some oral cancer.[16] The current paper seeks to shed light on the uses and applications of IONPs in different dental areas.

Iron Oxide Nanoparticle in Dentistry

Due to its intrinsic properties as diagnostic and/or chemotherapeutic drugs for diseases, metal nanoparticles like iron oxide, gold and silver nanomaterials are used and adjusted for dentistry purposes. With some application protocol, the following overview is supplied as an overview of some metal nanoparticles.[17,18] In biology and medicine, the iron component (FeOx) nanoparticle plays a significant role.[19] Because of its biocompatibility and non-poisonous properties to people, magnetite and maghemite, those two basic types of iron oxide nanoparticles, are generally well known in biomedical science.[20] In addition, iron oxide has been well able to decompose and thus beneficial for applications *in vivo*.[21]

Nanoparticles centered on Super-paramagnetic iron oxide are by far the most used NPs in medical science. Because of the guarded layer of exopolymers which embed microorganisms into a lattice which is impervious for insusceptible cells yet to numerous anti-infection agents, bacterial biofilms onto dental inserts are hard to kill by anti-toxins.[22,23] At current, the nanoparticulate compound is utilized to screen microbial contaminations. Iron-oxide nanoparticles have been used extensively on dental work to eradicate biofilm formation.[24]

Drugs Bound to IONPs

Attractive nanoparticles get a more prominent responsive zone and natural obstruction crossing potential than their micrometric reciprocals, which help their utilization during drug conveyance frameworks.[25] Various classes of medications could be straightforwardly bound to IONPs or fundamental nanosystems in this sense.[26,27] Such binding may occur via

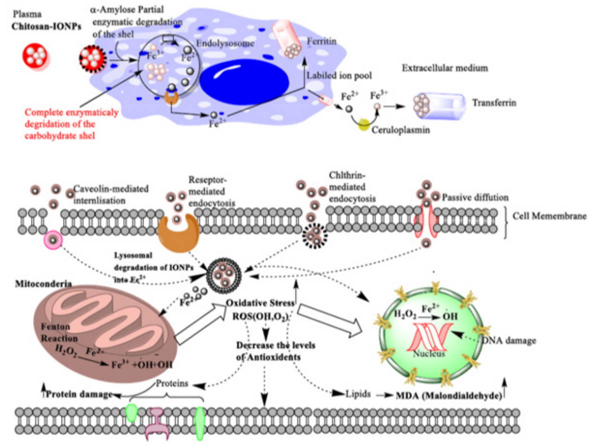

Figure 2: Schematic representation of different intracellular uptake pathways of ionps and chitosan-ionps.[1]

adsorption, polymers dispersion, nucleus encapsulation, electrostatic forces and surface cellular mechanisms, with the intention of improving their physicochemical effects. In carriers of anti-cancer, alternate.[10,15,28] Although the antibacterial role of IONPs is still unknown, some aspects of IONPs have been identified as having antibacterial activity.[29] Iron oxide can act on various bacterial cell materials.[30]

By electrostatic attraction and attraction to sulfur proteins, such ions tend to bind to both the cell wall and cytoplasmic membrane.[31] This increases membrane fluidity and also contributes to the destruction of these frameworks.[32] Porins in the cell wall are also involved throughout the taking up for IONPs in gram-negative bacteria. DNA, proteins and lipids contain bacterial components that can be destroyed by IONPs.[33,34] IONPs also stimulate the response to oxidative stress, causing the death of bacterial cells and enhanced phosphorylation, impeding bacterial growth and performance, of tyrosine residues onto bacterial peptide substrates.[35] The key agent, according to the literature, is cell membrane disruption caused by DNA modification caused by reactive oxygen species (ROS).[36]

Oral cavity bacterial are ideally arranged in biofilms that confer better environment for life, immuno-logical escape and infectious diseases. In particular, the preparation of nanomaterials in dentistry should take into account the mechanisms of iron ions released from IONPs toward bacteria.[37] These involve (i) interaction with both the cellular membrane of the peptidoglycan, thereby triggering cell lysis,[38] (ii) interaction with microbial (cytoplasmic) DNA, blocking replication of DNA,[39] and (iii) interaction with others and disturbing protein synthesis of bacterial proteins.[40]

The characteristics of the nanoparticle can influence its performance and interfere including its mode of action.[41] (I) the dispersion of nanomaterials in the biofilm exhibits a backwards connection between viability with size;[42] nanoparticles more than 50 nm are likewise not fit for infiltrating the biofilm given the general coefficient of self-dissemination all through the biofilm.[43] This declines dramatically with both the square of both the measurement of the nanoparticle. In correlation,[44,45] (ii) charged nanoparticles would not spread effectively through to the biofilm, possibly because of bacteria on the surface for phosphoryl and carboxyl groups, giving the cell layer an electronegative characteristic.[46,47] Many Researchers have discovered that coating dental implants with a lower concentration of poly D,L-lactic-co-glycolic acid (PLGA) (Ag-Fe_3O_4) under an extracorporeal magnetic field could improve biological compatibility while having little effect on antibacterial efficacy.

The magnetic field was generated as close to the PLGA (Ag–Fe_3O_4) as possible with a permanent magnet, and then applied in vivo to the implanted tooth with a permanent magnet.[48] As a result, Ag adheres to the tooth surfaces without being removed by ushing spray. Bacterial infections, such as those induced by Streptococcus mutants, activated the development of ROS by the host immune system, destroying the tooth-supporting tissues.[49] Bacterial adhesion was compromised in the embedded tooth coated with PLGA (Ag-Fe_3O_4). As a result, the immune system did not develop ROS, and the microenvironment around the implanted region caused osteoblast proliferation, improving transplant success rates.[44]

Other researchers developed iron oxide NPs with calcium phosphate cement scaffolds (IONP-CPC) that improved osteogenic differentiation of human dental pulp stem cells (hDPSCs) into IONP-CPC scaffolds significantly.[11] IONPs improved CPC properties such as wetting, protein absorption, and cell binding and spreading. The incorporation of IONP into CPC significantly improved the osteogenic distinction of hDPSCs.[45] The behaviors of alkaline phosphatase (ALP) and the expression of the osteogenic gene also improved significantly. In addition to the mineral without IONPs, the bone matrix mineral synthesized by the cells was improved two to threefold.[50] The IONP-CPC scaffold nanotopography and IONPs releases and intakes inside the cell were attributed to improved cell activity. The recently designed IONP-CPC scaffolds showed remarkable advances in osteogenesis, suggesting that they could be useful for bone tissue engineering and regenerative medicine applications.[22]

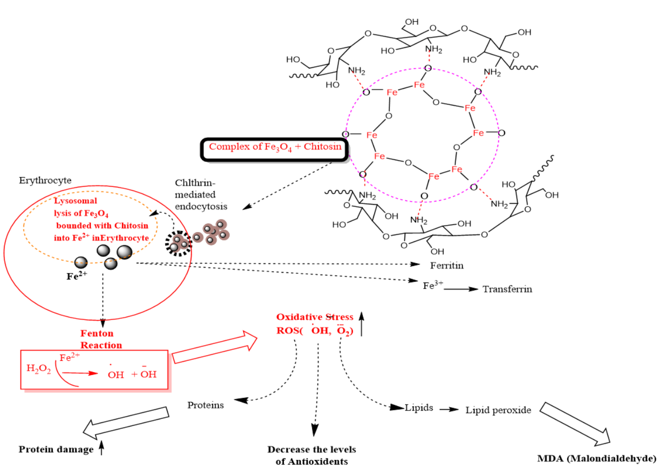

Figure 3: Suggested schematic of lysis IONPs by Lysosomes in cells with fenton reaction and general pathways of Fe II, III Ions

Antibiotics

The rise of amazingly safe microorganism strains and furthermore the decreased options in contrast to standard anti-microbials has stimulated interest inside the style of antimicrobial transporter nanosystems. IONPs functionalized with the metallic component are utilized as transporters of anti-infection agents.[12] As an actual blend, this anti-toxin showed a snappy delivery (20 minutes) in phosphate-padded saline, however inside such a nanosystem its full conveyance was done only once 530 minutes, exhibiting the flexibility of IONPs to act in controlled-release structures.[33]

True sorption to silver nanoparticles (Ag)-stacked IONPs ensured different groups of antimicrobials (rifamycin, anthracycline, fluoroquinolone, bactericide, and cephalosporin).[44]. It is accepted that silver (decidedly charged) communicates electrostatically with the IONPs, permitting connecting of those anti-infection agents Additionally, rifampicin, antimicrobial, cefotaxime, and Mefoxin were conjointly snared to IONPs adorned with silver, and furthermore the instruments of affiliation differed for each sort of anti-toxin, along with power restricting with negative locales and component restricting. Blend misuse the unpracticed sonication-helped technique was gone after for the beginning of the nanosystem IONPs-Ag-rifampicin. Sorption of rifampicin was evaluated at absolutely exceptional Ag centers (5.3, 7.7, 10.1, 15.1 mass%) inside the IONPs-Ag nanocomposite, and besides the most negligible and most imperative sorption occurred for silver at 5.3 and 7.7 mass%, severally.[24]

Different models of helpful assets have conjointly been contemplated, along with IONPs-ciprofloxacin nanosystem, which can be functionalized with milk sugar particles, additionally, nanosystems made out of amikacin, penicillin, bacitracin, cefotaxime, Erythrocin, gentamicin, kanamycin, neomycin, penicillin, polymyxin, hostile to disease specialists, and against microbial medicine direct coupled to IONPs are researched. Antifungals Fungal sicknesses are timeserving contaminations that typically affect upset patients and, if not appropriately treated, will be deadly. Since antifungal specialist (NYS) is one in everything about preeminent normally utilized fungicides, Hussein-Al-Ali *et al*. prepared a nanosystem made out of IONPs, CS, and NYS. The creators are incontestable that the release profile of NYS in an incredibly actual combination of those secluded mixtures endured concerning twenty min, diverged from 1800 min of the IONPs-CS-NYS nanosystem. This qualification will be explained by the force cooperation between NYS (oppositely charged) and metallic segment (decidedly charged), by that it will be found that the IONPs-CS-NYS nanosystem was set up to deliver a controlled arrival of NYS.[43]

Ketoconazole and hostile to microbial B are different antifungal prescription that is attempted inside the headway of appealing nanosystems to lessen their viewpoint impacts and improve antifungal action. Ketoconazole was coupled to epoxy-functionalized IONPs immobilized with HSA, and its restricting part occurred through hydrophobic coordinated effort, while amphotericin B was clearly incomparable to IONPs by a reaction among aminoalkane and normal compound gatherings, independently from the antifungal drug Antimicrobial Activity of IONPs-Based Nanosystems Studies counsel that the capacity of alluring nanoparticles to think of microbic harmfulness is because of a progression of collaborations, along with layer change with resultant hindrance of cell honesty, creation of receptive nuclear number eight species (ROS) with lipide peroxidation and deoxyribonucleic corrosive harm, and release of metal particles that influence cell physiological state and macromolecule coordination. The joining of IONPs-based nanosystems into clinical gadgets has shown promising outcomes in regards to the restraint of microbic settlement. tube surfaces covered with fundamental oils-stacked IONPs cut introductory cell bond of *S. aureus* and enterics pneumonia, with a lesser outcome on more developed phases of biofilm arrangement. Thus, covering material filaments of twisted dressings with patchouli fundamental oil-connected IONPs successfully decreased the amount of *S. aureus* biofilm cells.[28]

In any case, concerning normal mixtures, gallic corrosive covered IONPs were appeared to display comparative antimicrobial impacts contrasted with Polycillin, anti-toxin and antifungal specialist against *E. coli,* eubacteria subsites, and organism family niger, severally. Notwithstanding the positive results outlined on top of, clashing outcomes were reputed for various nanosystems. While a nanosystem made out of IONPs, dry milk sugar (SDL), an anti-toxin was appeared to diminish the full biomass and metabolic movement of microorganisms family aeruginosa biofilms (with partner expanded outcome advanced by an attractive field). Troublesome outcomes were conjointly revealed for *P. aeruginosa*, inside which IONPs advanced incitement of biofilm development

Other Clinical Application of IONPs

Medication transporters have conjointly been tried to battle the obstruction of oral biofilms to industrially offered medication. sterile (CHX), a partner antimicrobial specialist familiar with the executive oral biofilms, was demonstrated to be less difficult once total to IONPs in diminishing biofilm biomass of *S. aureus, E. faecalis,* and *Candida albicans*, differentiated, and the medicine applied alone. In addition, CHX particles functionalized with IONPs inhibited *Porphyromonas gingivalis* expansion, and when combined with HEMA-UDMA rosin plates, a CHX discharge mechanics influenced by field was discovered.[48-50]

Because of their physicochemical properties, such as surface charge, property, and high scope quantitative relation by volume, nanoparticles are thought to have the potential to pick up and penetrate biofilms. Charged and unbiased IONPs advanced the higher decrease of cells of Streptococcus freaks biofilms concerning charged partners. The antibiofilm movement of attractive nanoparticles is influenced by their surface properties. IONPs also have a real-world use as catalysts, with names like material shift (IONPs-CAT) and chemicals. In collaboration with H_2O_2, IONPs-CAT demonstrated partner-expanded antimicrobial outcomes. *In-vitro*, mutans biofilms outperformed its partner but not H_2O_2.

Beneath *in-vivo* conditions, IONPs-CAT weakened tooth rot commencement and the seriousness of injuries, while H_2O_2 alone did not display impressive impacts, showing the capability of the IONPs in battling holes. Ends and perspectives Microorganisms confirmation against common medicines advances faster than the formation of the most recent medication and anti-toxins. Inside this specific circumstance, IONPs bear the decent potential to be utilized in nanosystems equipped for defeating the actual hindrances of the microbic biofilm framework in conveying the medication to the objective. Succeeding advances comprise investigating the attractive properties of IONPs to support the medication result abuse lower focuses, in this way decreasing viewpoint impacts and harmfulness. The different blend techniques have permitted the making of nanoparticles with totally various sizes, constructions, scatterings, and surface changes.[44]

Be that as it may, as wide varieties are accounted for among totally extraordinary investigation conventions, and on the spot correlation of the outcomes is impossible. These side focuses curved the need for refinement/standardization of blend application 2018 7, 46, 18 of 32 and functionalization prior to *in vivo* research, to produce nanoparticles with adequate consistency, size regulation, biocompatibility, and bioavailability. Notwithstanding the developing assortment of logical confirmation on the work of IONPs in medication conveyance frameworks, not all pertinent medication of clinical/dental premium are examined, either alone or alongside IONPs. In this regard, the emergence of novel IONPs-based nanosystems arranged to pass on various prescriptions while maintaining palatable delivery of the heads on the target tissues may be crucial in several clinical situations. These typify the evasion/control of infections related to various microorganisms (e.g., microorganisms and growths), likewise to conditions that need various classes of medications (e.g., against inflammatories, anti-toxins, and antifungals)

At last, identifying with the relevance of IONPs-based nanosystems, most clinical primers drove so far have zeroed in on tomography, so clinical assessment of employments isolated from tomography is foreseen soon. For such purposes, goliath and mechanical scale formation of IONPs-based nanosystems is a pivotal test to be survived.[44-50]

CONCLUSION

Biomedical scientists and physicians worldwide are working to improve public health through preventive and early intervention. Nanotechnology is expected to significantly affect dental testing and treatment methodologies shortly, contributing to superior oral health care. Nanomaterials can be used more often and have better properties; laser and digital-led surgery can provide excellent dental care when combined with biotechnology. To stop craniofacial disorders, nanodiagnostics, smarter preventive methods, and earlier therapies seem possible. Nanotechnology research will inevitably pave the way for creating instruments that will aid clinicians in the early detection and treatment of oral cancers. We can now bioengineer missing teeth and remineralize carious lesions using biomimetics and nanotechnology.

Researchers in the fields of dentistry and nanotechnology are interested in this area. Salivary glands can act as a portal into the body to deliver specific molecular therapies through drug delivery systems based on nanoparticles that have fewer side effects. Saliva can be used by predictive instruments such as "lab-on-a-chip" to identify dental and other physical anomalies in the human body. Dental composite materials now have better esthetic, thermal, and mechanical properties thanks to nanofillers. These theories may seem outlandish, but discoveries have always resulted from outlandish science concepts.

REFERENCES

1. Jubran AS, Al-Zamely OM, Al-Ammar MH. Estimation of iron oxide nanoparticles on white albino mice induced with iron deficiency anemia. Drug Invention Today, 2019;11(11):2880-2886.
2. Ansari L, Shiehzadeh F, Taherzadeh Z, Nikoofal-Sahlabadi S, Momtazi-Borojeni AA, Sahebkar A, Eslami S. The most prevalent side effects of pegylated liposomal doxorubicin monotherapy in women with metastatic breast cancer: a systematic review of clinical trials. Cancer Gene Ther. 2017 May;24(5):189-193.
3. Onnainty R, Onida B, Páez P, Longhi M, Barresi A, Granero G. Targeted chitosan-based bionanocomposites for controlled oral mucosal delivery of chlorhexidine. Int. J. Pharm. 2016 Jul 25;509(1-2): 408-418.
4. Anselmo A, Mitragotri S, A review of clinical translation of inorganic nanoparticles. AAPS 2015;17(5):1041-1054.
5. Nigam S, Bahadur D. Doxorubicin-loaded dendritic-Fe3O4 supramolecular nanoparticles for magnetic drug targeting and tumor regression in spheroid murine melanoma model. Nanomedicine: Nanotechnology, Biol. Med. 2018 Apr 1;14(3):759-768.
6. Apopa PL, Qian Y, Shao R, Guo NL, Schwegler-Berry D, Pacurari M, Porter D, Shi X, Vallyathan V, Castranova V, Flynn DC. Iron oxide nanoparticles induce human microvascular endothelial cell permeability through reactive oxygen species production and microtubule remodeling. Part. Fibre Toxicol. 2009 Dec;6(1):1-4. doi: 10.1186/1743-8977-6-1.
7. Anselmo AC, Prabhakarpandian B, Pant K, Mitragotri S. Clinical and commercial translation of advanced polymeric nanoparticle systems: opportunities and material challenges. Transl. Mater. Res. 2017 Feb 7;4(1):014001.
8. Bernabeu E, Cagel M, Lagomarsino E, Moretton M, Chiappetta D, Paclitaxel: what has been done and the challenges remain ahead. Int. J. Pharm. 2017;526(1-2):474-495.
9. Hussain N, Alwan S, Alshamsi H, Sahib I. Green Synthesis of S- and N-Codoped Carbon Nanospheres and Application as Adsorbent of Pb (II) from Aqueous Solution. Int. J. Chem. Eng. 2020;13.
10. Bhattacharyya J, Bellucci JJ, Weitzhandler I, McDaniel JR, Spasojevic I, Li X, Lin CC, Chi JT, Chilkoti A. A paclitaxel-loaded recombinant polypeptide nanoparticle outperforms Abraxane in multiple murine cancer models. Nat. Commun. 2015 Aug 4;6(1):1-2.
11. Chawla SP, Chua VS, Fernandez L, Quon D, Blackwelder WC, Gordon EM, et al., 2010. Advanced phase I/II studies of targeted gene delivery in vivo: intravenous rexin-g for gemcitabine-resistant metastatic pancreatic cancer. Mol. Ther. 2010;18:435-441.
2. Chen Y, Yue Q, De G, Wang J, Li Z, Xiao S, et al., Inhibition of breast cancer metastasis by paclitaxelloaded pH responsive poly(β-amino ester) copolymer micelles. Nanomedicine 2017;12 (2):147-164.
13. Chowdhury A, Kunjiappan S, Panneerselvam T, Somasundaram B, Bhattacharjee C, Nanotechnology and nanocarrier-based approaches on treatment of degenerative diseases. Int. Nano Lett. 2017;7(2):91-122.
14. Davis ME, Zuckerman JE, Choi CH, Seligson D, Tolcher A, Alabi CA, Yen Y, Heidel JD, Ribas A. Evidence of RNAi in humans from systemically administered siRNA via targeted nanoparticles. Nature. 2010 Apr;464(7291):1067-1070.
15. Bandhu A, Sutradhar S, Mukherjee S, Greneche JM, Chakrabarti PK, Synthesis, characterization and magnetic property of maghemite (g-Fe_2O_3) nanoparticles and their protective coating with pepsin for bio-functionalization. Mater. Res. Bull. 2015;70:145e154.
17. Bhowmick A, Saha A, Pramanik N, Banerjee S, Das M, Kundu PP. Novel magnetic antimicrobial nanocomposites for bone tissue engineering applications. RSC Advances. 2015;5(32):25437-25445.
18. Eifler AC, Thaxton CS. Nanoparticle therapeutics: FDA approval, clinical trials, regulatory pathways, and case study. InBiomedical nanotechnology 2011;325-338. Humana Press.
19. Cicha I., Scheffler L., Ebenau A., Lyer S., Alexiou C., Goppelt-Struebe M. Mitoxantrone-loaded superparamagnetic iron oxide nanoparticles as drug carriers for cancer therapy: Uptake and toxicity in primary human tubular epithelial cells. Nanotoxicology. 2016;10:557-566.
20. Eitan, R., Fishman, A., Meirovitz, M., Goldenberg, H., Amit, A., Koren, C., et al., Liposome-encapsulated doxorubicin citrate (Myocet) for treatment of recurrent epithelial ovarian cancer. Anticancer Drugs 2014;25(1):101-105.
21. Csaba, P.C., Papp, B., Lazar, V., Collateral sensitivity of antibiotic-resistant microbes. Trends Microbiol. 2015;23:401-407.
22. Elzoghby, A., Samy, W., Elgindy, N., Albumin-based nanoparticles as potential controlled release drug delivery systems. J. Controlled Release 2012;157(2):168-182.
23. Mendes R, Fernandes AR, Baptista PV. Gold nanoparticle approach to the selective delivery of gene silencing in cancer—the case for combined delivery?. Genes. 2017 Mar;8(3): 94.
24. Istrate C.M., Holban A.M., Grumezescu A.M., Mogoantă L., Mogoşanu G.D., Savopol T., Moisescu M., Iordache M., Vasile B.S., Kovacs E. Iron oxide nanoparticles modulate the interaction of different antibiotics with cellular membranes. Rom. J. Morphol. Embryol. 2014;55:849-856.
25. Mieszawska, A.J., Mulder, W.J.M., Fayad, Z.A., Cormode, D.P., 2013. Multifunctional gold nanoparticles for diagnosis and therapy of disease. Mol. Pharm. 10, 831-847.
26. Ebrahiminezhad A, Rasoul-Amini S, Davaran S, Barar J, Ghasemi Y. Impacts of iron oxide nanoparticles on the invasion power of Listeria monocytogenes. Current Nanoscience. 2014 Jun 1;10(3):382-388.
27. Banerjee R. Nanotechnology in drug delivery: present status and a glimpse into the future. Ther. Deliv. 2018;9(4):231-232.
28. Comănescu MV, Mocanu MA, Anghelache L, Marinescu B, Dumitrache F, Bădoi AD, Manda G. Toxicity of L-DOPA coated iron oxide nanoparticles in intraperitoneal delivery setting—

Preliminary preclinical study. Rom J Morphol Embryol. 2015 Jan 1;56(2 Suppl):691-696.

29. El Zowalaty, ME, Hussein Al-Ali, SH., Husseiny MI, Geilich, BM, Webster TJ, Hussein MZ, The ability of streptomycin-loaded chitosancoated magnetic nanocomposites to possess antimicrobial and antituberculosis activities. Int. J. Nanomed. 2015;10:3269-3274.
30. Emst TM. Fehling H, Bernin H, Zaruba MD, Bruchhaus I, Adam G, Ittrich H, Lotter H, Magnetic resonance imaging of pathogenic protozoan parasite Entamoeba histolytica labeled with superparamagnetic iron oxide nanoparticles. Invest. Radiol. 2015;50:709-718.
31. Conde J, Ambrosone A, Sanz V, Hernandez Y, Marchesano V, Tian F, et al., Design of multifunctional gold nanoparticles for in vitro and in vivo gene silencing. ACS Nano 2012;6:8316-8324.
32. Cucinotto, I., Fiorillo, L., Gualtieri, S., Arbitrio, M., Ciliberto, D., Staropoli N, et al., Nanoparticle albumin bound paclitaxel in the treatment of human cancer: nanodelivery reaches prime-time? J. Drug Deliv. 2013:1-10.
33. Aljeboree AM. Adsorption and removal of pharmaceutical riboflavin (RF) by rice husks activated carbon., International Journal of Pharmaceutical Research, 2019;11(2):255-261
34. Wierzbinski KR, Szymanski T, Rozwadowska N, Rybka JD, Zimna A, Zalewski T, et al., otential use of superparamagnetic iron oxide nanoparticles for in vitro and in vivo bioimaging of human myoblasts. Sci. Rep. 2018;8:1-17.
35. Qiu TA, Bozich JS, Lohse SE, Vartanian AM, Jacob LM, Meyer BM, et al., Gene expression as an indicator of the molecular response and toxicity in the bacterium Shewanella oneidensis and the water flea Daphnia magna exposed to functionalized gold nanoparticles. Environ. Sci. Nano 2015;2:615-629.
36. He X, Smeets RL, Koenen HJ, Vink PM, Wagenaars J, Boots AM, Joosten I. Mycophenolic acid-mediated suppression of human CD4+ T cells: More than mere guanine nucleotide deprivation. Am. J. Transpl. 2011;11:439-449.
37. Abu Mukh-Qasem, R., Gedanken, A., Sonochemical synthesis of stable hydrosol of Fe_3O_4 nanoparticles. J. Colloid Interface Sci. 2005284:489-494.
38. Ragelle, H., Danhier, F., Pre´at, V., Langer, R., Anderson, D.G., 2017. Nanoparticle-based drug delivery systems: a commercial and regulatory outlook as the field matures. Exp. Opin. Drug Deliv. 14, 851-864.
39. Daep CA, Novak EA, Lamont RJ, Demuth DR. Structural dissection and in vivo effectiveness of a peptide inhibitor of Porphyromonas gingivalis adherence to Streptococcus gordonii. Infect Immun. 2011;79(1):67-74.
40. Rana S, Bajaj A, Mout R, Rotello V, Monolayer coated gold nanoparticles for delivery applications. Adv. Drug Deliv. Rev. 2012;64(2):200-216.
41. Pusic K, Aguilar Z, McLoughlin J, Kobuch S, Xu H, Tsang M, et al., Iron oxide nanoparticles as a clinicallyacceptable delivery platform for a recombinant blood-stage human malaria vaccine. FASEB 2013;27(3):1153-1166.
42. de Sousa FF, Ferraz C, Rodrigues LK, Nojosa Jde S, Yamauti M. Nanotechnology in dentistry: drug delivery systems for the control of biofilm-dependent oral diseases. Curr Drug Deliv. 2014;11(6):719-728.
43. Lafond JF, Shimoji M, Ramaswamy B, Shukoor MI, Malik P, Shapiro B, Depireux DA. Middle ear histopathology following magnetic delivery to the cochlea of prednisolone-loaded iron oxide nanoparticles in rats. Toxicol. Pathol. 2018;46: 101-106.
44. Reddy, U., Prabhakar, P., Mahboob, M., 2017. Biomarkers of oxidative stress for in vivo assessment of toxicological effects of iron oxide nanoparticles. Saudi J. Biol. Sci. 24 (6), 1172-1180.
45. Paladini, F., Pollini, M., Sannino, A., Ambrosio, L., Metal-based antibacterial substrates for biomedical applications. Biomacromolecules 2015;16:1873-1885.
46. Unterweger H., Subatzus D., Tietze R., Janko C., Poettler M., Stiegelschmitt A., Schuster M., Maake C., Boccaccini A.R., Alexiou C. Hypericin-bearing magnetic iron oxide nanoparticles for selective drug delivery in photodynamic therapy. Int. J. Nanomed. 2015;10:6985–6996.
47. Aljeboree, A.M., Abbas, A.S., Removal of Pharmaceutical (Paracetamol) by using CNT/ TiO_2 Nanoparticles. J. Glob. Pharma Technol. 2019;11(1):199-205.
48. Aljeboree AM, Alkaim AF. Photocatalytic Degradation of Textile Dye Cristal Violet Wastewater using Zinc Oxide as a Model of Pharmaceutical Threat Reductions. J. Glob. Pharma Technol. 2019;11(3):138-143.
49. Aljeboree AM, Alkaim AF. Removal of Antibiotic Tetracycline (TCs) from aqueous solutions by using Titanium dioxide (TiO2) nanoparticles as an alternative material. J. Phys. Conf. Ser. 2019 Sep 1 1294(5)"052059). IOP Publishing.
50. Sahib IJ, Jasim LS, Alkaim AF. Synthesis and characterizations of reduced graphene oxide/iron oxide: as a model of water treatment. International Journal of Applied Engineering Research. 2017;12(24):14874-14877.