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REVIEW ARTICLE

Some Biological and Biomedical Effects of Nanoparticles

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Abstract

During the last decade, huge improvement in nanobiotechnology and nanomaterials production resulted in different forms of nanoparticles (NPs) with a huge potential for health-related applications that remain understudied. Such applications extend beyond a direct human effect and could be mediated via impacting the environmental conditions, livestock production, and even the outbreak of certain diseases. Evidently, the increased growth in the production of such nanomaterials along with their understudied effects/ potential on human health represents a major side effect of nanotechnology. Such limitations include not fully identified bio-distribution and the physiological/ toxicological impacts on the different body organs as well as cellular activity upon exposure. NPs are very small in size (1 to 100 nm) and are found in different forms. There are various classifications of NPs depending on their size, shape, and properties. NPs have special physical and chemical characters as a result of possessing a large surface area and nanoscale size. The lack of proper safety assessment studies of such NPs, both in vitro and in vivo, as well as the shortage in biodistribution/ adverse effects and mechanisms represents a major concern. This brief review attempts to outline and correlate reports on several NPs and their application in the medicine and biology as well as summarizing any discrepancies in experimental conditions, toxicity, biohazard, and safety of NPs in different organs.

Keywords: Nanoparticles, Nanotechnology, Biomedical applications, Biohazards

Introduction

Recently, nanotechnology has gained obvious momentum, in spite of not being a modern notion. The prefix "Nano" implies one-billionth as a nanometer equals one-billionth of a meter following the metric scale of linear measurements. Profoundly, nanotechnology refers to the synthesis of any material with a nano scale of dimensions ranging between 1 and 100 nm [1]. However, with its progression, the scope of such definition was extended. Nanoparticles (NPs) of various sizes have diverse biomedical utilizations. Whitesides has elegantly explored and clarified the link between nanotechnology, biology and chemistry [2]. Such relationship starts with the synthesis of different NPs, followed by characterization and in-depth assessment of the potential effects both in vivo and in vitro of such NPs and finally promoting certain potential applications (Figure 1).

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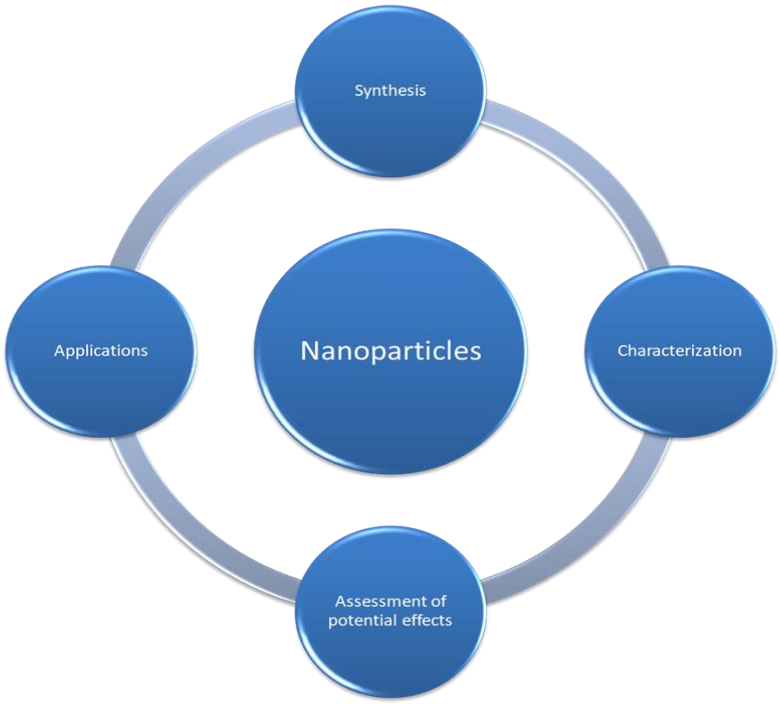

Figure 1. The lifecycle of nanoparticles.

Nanotechnology is recently utilized as a tool to investigate the potential ways for therapeutic application in a few different ways, for example, imaging [3], sensing [4], targeted drug delivery [5], gene delivery systems [6], and artificial implants [7]. Such drugs are NPs of polymers, metals, or ceramics, that could conflict conditions such as cancer [8] and combat human pathogens such as bacteria [9, 10]. Applying nanotechnology in diagnosis, monitoring, treatment, and diseases control gave rise to a new branch named nanomedicine. Although medically related nanotechnological application appeared to be a moderately ongoing current, the fundamental nanotechnological approaches for medicinal application goes back to quite a few years.

Nanotechnology derived products have become widely useful in biomedicine and this promoted the introduction of a hybrid science called nanobiotechnology [11]. Nanomaterials have notable applications in nanobiotechnology, especially in diagnosis and drug delivery system implants and prostheses [12]. Nanoscale materials incorporate well in different biomedical gadgets/ devices due to the nanosized nature of the different biological systems. These nanomaterials normally include inorganic and metal NPs, carbon nanotubes, liposomes, and metallic surfaces [13].

Bio-specific molecules may be mixed with NPs via utilization of chemical or physical approaches and taking advantage of specialized biological processes, such as antibody-antigen interaction, receptor-ligand interaction, and DNA-DNA hybridization [14]. In addition to surface physics [15,16] and thermodynamics [17], the toxicological impacts decide the particular use of nanomaterials [18]. In this context, we attempt to focus on the utilization of inorganic e.g. (metallic and metal oxide) and organic e.g. (carbon-nanotubes and liposomes) NPs in the biomedicine. Also, NPs induced toxicity is additionally explained.

Metal oxide and metallic nanoparticles

Metal oxide NPs were utilized to create different medical tools. Metal oxide NPs represent a promising tool for biomedical applications because they are characterized by their higher stability, simpler preparation processes, simple engineering to the wanted size, shape and porosity, simple incorporation into hydrophobic and hydrophilic systems and easy functionalization due to the negative charge on the surface [19]. The iron oxide magnetic characteristics had been utilized for

diagnosis and therapy related purposes, for example, in magnetic resonance imaging magnetic particle are used as imaging contrast agents, and ultrasonic techniques for example magnetomotive ultrasound [20], magnetic particle hyperthermia and photo acoustic imaging [21]. The zinc oxide (ZnO) electronic structure is significant for biomedical purposes; for instance, imaging cancer cells via utilizing ZnO intrinsic fluorescence nanowires [22]. Likewise, the ZnO nanowires surface functionalization augmented their solubility in water, biocompatibility, and diminished their cellular toxicity. The ZnO surface functionalization with special biomolecules makes photosensitive biosensors [23]. Alternatively, titanium oxide (TiO_2) has a wide variety of biomedical uses [24]. For instance, in materials used for bone-substitution [25]. Also, the potential use of TiO_2 NPs for regeneration of bone has been suggested [26]. Zirconium oxide can be also used for dental implants owing to, similar to titanium, its compatibility with hard tissues [27].

Metallic NPs represent an interesting field biomedical sciences and engineering research. Such materials can be synthesized and altered with different chemical functional groups, thus allowing their conjugation with antibodies or drugs. Collectively, this opens wide range of applications in biotechnology, diagnostic imaging, magnetic separation, targeted drug and vehicles for gene delivery. The implementation of this innovation relies upon the geometry and size of the particles as these decide their different characteristics. Nano-gold are used to examine the blood flow *in vivo* via using photograph acoustic imaging [28,29] in the form of nano spheres, nano shells and nano cages [30]. It is possible to amend the surface of nano-gold by compounds that poses sulfur due to the higher chemical affinity of both sulfur and gold [31].

Gold NPs modification with bio-specific compounds reinforces the binding to specific tissues [12]. For instance, surface-labelled gold nano shells had been utilized to *in vitro* targeting of cancer cells [28]. Different polymers used as wound dressing [32] and bone cement [33], also have been carried on AgNPs and their antimicrobial effect are promising. AgNPs-bone cement combines powerful antibacterial action with low cytotoxic effects in comparison with gentamicin and silver salt bone cement [33]. Controlling molecule delivery via decreasing their size is a proper approach to diminish toxicity. AgNPs addition to latex membranes can be utilized for skin recovery [34] with the membranes controlling the nanoparticle delivery rate [35]. The different effects of NPs in the view of the available literature are compiled in Table 1.

Table 1. Dose related changes following Experimental nanoparticle administration

Type of nanoparticle	Administration	Effect	Reference
Cerium oxide nanoparticles	50, 100, 200, and 400 mg/kg BW/day intraperitoneally CNPs for 14 consecutive days	↓liver and kidney function parameters	[101]
	30, 300 and 600 mg/kg BW/day orally daily for 28 days	↑LDH ↓GSH ↑ALP	[102]
	0.15, 0.5, 1.0, 3.5 or 7 mg/kg BW/day via intratracheal instillation	↑ TIMP-1 ↓MMP-9 ↑Hydroxyproline	[103]
Copper oxide nanoparticles	5, 50 mg/kg BW/day via oral gavage orally for 14 days. control group https://doi.org/10.1016/j.toxrep.2018.08.022 Received 30 July 2018; Received in revised form 16 August 2018; Accepted 29 August 2018 * Correspondence to: Department of Pharmacology, Jyothishmathi Institute of	Oral administration of NPs (with 5, 50 mg/kg b.w) to rats caused significant (P < 0.05) al- terations in antioxidant enzyme activities. It was	[104]

	Pharmaceutical Sciences, Beside LMD Police Station, Nusthulapur, Karimnagar, 505481, India	found the significant dose dependent decrease ($p < 0.05$) in GSH, Catalase (CAT) and SOD activity, whereas the lipid peroxidation product (MDA) levels were increased ($p < 0.05$). Statistically significant reduction in reduced glutathione, catalase and SOD activity represents the reduction of antioxidant enzyme levels following exposure of CuO nanoparticles and significant increase in lipid peroxidation levels indicate the tissue damage and oxidative stress. ↓GSH ↓CAT ↑ MDA	
	50, 100, and 200 mg/kg BW/day via oral gavage	200CuNPs ↑ ALT ↑ AST ↓CYP450	[105]
Silver nanoparticles	Rats given 5.36 and 13.4 mg/kg BW of AgNPs for six months.	↓SOD ↑MDA level. ↓DNA chromatin integrity %	[106]
	5 and 0.0003 mg/kg BW for AgNP IV at 24 h before sacrifice.	↑ALT, ↑ BUN, ↑TBil ↑Creatinine	[107]
	intraperitoneally with Ch-AgNPs each day for 14 days at doses of 50, 25, and 10 mg/kg BWt, respectively.	↑MDA ↑ALT ↑AST ↓GSH ↓IgG ↓IgM ↓TP	[108]
	30, 300 and 1000 mg/Kg doses of AgNPs (60 nm),28 days of oral administration	↓NF-kB ↓ bcl-2 ↑caspase-3	[109]
	515 g/m3, (6 h/day, 5days/week for 13 weeks), inhalation	↑albumin ↑LDH ↑ TP	[110]
	rBMEC 6.25–50 µg/mL, (25, 40 or 80 nm in size), (24 h)	↑ IL1β, ↑ IL-2 ↑TNF-α ↑ PGE-2	[111]

	A431 (human skin carcinoma) 50 and 100 mg/mL, (24 h)	↑ROS	[110]
	Pancreas cancer BxPC-3 Cells AgNPs (100 µg/mL), (24 h)	↑ROS	[112]
Zinc oxide nanoparticles	50, 100, 150 and 200 mg zinc oxide NPs (nZnO)/kg BW/day intraperitoneally daily for ten days	nZnO150 ↑SOD ↑GPX activity, nZnO200 ↑ MDA ↑ TOS when nZno200 ↓ TAC	[113]
	500, 1000, and 2000 mg/Kg BW/day for 14 days.	↓ B.wt ↓ FI ↑ WBCs ↑ NEUs	[114]
	Neuro-2A30–45 nm, (2–72 h)	↓LDH	[115]
	Human hepatocyte (L02) 100, 300 and 600 mg/Kg BW,(7 days)	↓SOD ↓ GSH	[116]
Selenium nanoparticles	0.2, 0.4, 0.8, 2.0, 4.0, or 8.0 mg Se/kg- BW/day orally daily for 14 days.	0.2 and 0.4 mg Se ↑B.wt2.0, 4.0, and 8.0 mg Se ↓B.wt	[117]
CNT	PC12 cells bPEG-SWCNTs at concentrations of 0.5, 2.1 and 1 mg/mL	↑GSH ↑ROS	[118]
	Human Dermal Fibroblast Cells10 µg/mL, (72 h)	↑ IL-8 ↑ROS	[119]
	Embryonic kidney cells (HEK293) 4 mg/Kg BW, (7 days)	↑ IL-8 ↑LDH	[120]

BW; body weight, LDH; Lactate Dehydrogenase, GSH; Glutathione, ALP; Alkaline phosphatase, TIMP-1; Tissue inhibitor matrix metalloproteinase 1, MMP-9; Matrix metallopeptidase 9, CAT; Catalase, MDA; Malondialdehyde, ALT; Alanine aminotransferase, AST; Aspartate Aminotransferase, CYP450; Cytochromes P450, SOD; Superoxide dismutase, BUN; Blood urea nitrogen, TBIL; Total bilirubin, Ig; immunoglobulin, TP; total protein, NF-kB; nuclear factor κB, bcl-2; B-cell lymphoma 2, rBMEC; primary rat brain microvessel endothelial cells , IL; interleukin, TNF-α; Tumor Necrosis Factor Alpha, PGE-2; Prostaglandin E2, ROS; reactive oxygen species, GPX; glutathione peroxidase, TOS; total oxidant status, TAC; total antioxidant capacity, FI; Food intake, WBCs; White blood cells, NEUs; neutrophils,

Zinc oxide nanoparticles

The improvement of biodegradable, biocompatible, and functionalized nanomaterials for biomedical applications had been an exceptionally dynamic research zone. Zinc oxide (ZnO) nanomaterials had increased huge importance for biomedical applications depended on these desirable properties. ZnO has novel optical and semiconducting characters [36,37]. ZnO-based nanostructures were researched for a wide range of application, for example, nano-sensors, energy capacity, nano-electronic and cosmetics [38-40]. ZnO nanomaterials can be utilized as semiconductors in microelectronic gadgets and used to accelerate water pollutant degradation by means of photo catalytic activity [41]. In view of its intrinsic capacity to absorb UV light and optical transparency, ZnO NPs are utilized in the cosmetic industry, normally, in facial creams and sunscreens [42,43]. Food and drug administration (FDA) had declared using of ZnO in sunscreens because of being stable and its natural capacity of absorbing UV light. Because of its antibacterial properties, different antimicrobial applications of ZnO were also encouraged. ZnO NPs have obtained importance for another biomedical application relied upon their high stability, and low toxic effect and biodegradability. The ZnO surface has more OH groups in its chemical formula, that could be effectively utilized [44,45]. ZnO slow disintegration in both acidic (for example

in the cancer microenvironment and cancer cells) and strong basic conditions is advantageous [46]. Also, several researches discussed the usage of ZnO nanomaterials in bio medicinal purposes, for example drug and gene delivery, biomedical imaging, and cancer treatment [47].

Silver nanoparticles

Nano silver or silver NPs (AgNPs are silver atoms clusters, which vary in diameter from 1 to 100 nm. AgNPs possess a huge potential for medicinal applications due their antimicrobial properties. Silver NPs flourishing research scale is now hugely commercialized. Nano-silver (NS) has been integrated by clothing manufacturers into fabrics for socks due to its antibacterial activity preventing the growth of odor producing bacteria [48,49]. Also, Nano silver has been incorporated into wide range of contact materials of food, for example, fabricating food containers by using plastics, surface of refrigerator, bags and cutting boards [50]. Such applications were linked to a longer preservation of foods via the microorganism growth inhibition. The medicinal applications, despite the slow start, NS in prophylaxis is currently gaining strength. Ongoing proof proposes that NPs has a powerful anti-inflammatory impact [32,51] and hastens wound healing [52,53]. Silver, in its original form, has been known to have antibacterial action and has been utilized since the beginning, from Hippocrates' initial ulcers treatment to cerebrospinal fluid (CSF) Crede's treatment for gonococcal diseases in babies. Silver sulfadiazine is the highest quality level in topical treatment of patients who have burns [53]. Growing interest for silver and Nano silver had increased due to the emersion of antibiotic resistant bacteria and the expansion of hospital acquired infections. Silver use is seriously constrained by human toxicity of silver particles, however, nanotechnology has simplified the synthesis of smaller particles of silver with progressively large surface area to-volume proportions, significant adequacy against bacteria [54,55] and, diminish toxicity of humans [56].

Selenium nanoparticles

Selenium is a trace element required for human wellbeing. Lately, the medical advantages of selenium have been progressively known and studied [57]. Selenium is found in the body of human as selenoproteins, from dietary natural or inorganic selenium. Natural selenium (essentially selenomethionine) and ionic selenium (e.g., selenite and selenate) are profoundly bioavailable, however elemental selenium is difficultly absorbed from the gastrointestinal tract except in nanosized [58]. Selenium as a pleiotropic mediator for delivery of drug and biotherapy has drawn much attention to the interpretation of Se-based nanomedicines. Selenium isn't just utilized as a dietary supplement to prevent and treat infection, but also it is used for drug delivery as NPs to improve the therapeutic effects of drugs [59,60]. A synergistic impact is expected between selenium and Se-loaded material.

based on the various biological activities and physiological impacts, SeNPs are widely used to manage oxidative distress, inflammatory disorders, Se-related thyroid disorders, viral disease, bacterial/fungal infection, detoxication, chemo/radiotherapy adjuvants, fertility improvement, medicinal analysis, and so forth [61].

Cerium oxide nanoparticles:

Cerium is rare earth metal with atomic number of 58. It considered the most ample rare earth metal, which possess two oxidation states [62]. Cerium oxide is a lanthanide metal oxide and is utilized in ultra violet absorption [63,64], as a catalyst [65,66], in gas sensors polishing [67,68]. From a commercial point of view, Nanoceria plays an important part in consumer and cosmetic products. Also, they act as excellent oxide conductors utilized in gas sensors [69]. Newly, Nanoceria related biomedical applications are emerging as they showed protection against cellular destruction mediated by toxicants, radiation and even during pathological states, for example, heart or brain ischemia, neurodegeneration of retina or neurological issue [70]. Naked nanoceria is poorly soluble in the water resulting in difficulties in biological applications. Numerous reports have pointed out a nanomaterials polymer covering could boost the biocompatibility, stability and solubility, for example, nanoceria covered with dextran exhibited antioxidant actions [71].

Nanoceria is getting discharged to the environment, human exposure has been found particularly through inhalation resulted in a significant concern. Paradoxical results are found in the different reports describing the toxicity of nanoceria. Few reports stated that nanoceria have low toxicity [72] that was not sufficient to induce cytotoxicity or inflammation [73].

On the other hand, proof from other studies explains that nanoceria induces cell death. They have pro-oxidative action because of reactive oxygen species (ROS) that trigger a damage of cell and even induce cellular death. A few *in vivo* or *in vitro* reports studied the induction of oxidative stress by nanoceria [74]. Interestingly, while nanoceria works directly as an antioxidant, also it behaves as free radical scavengers for free radical. This is due to the effect of hydroxyl radical, superoxide radical and hydrogen peroxide interaction which restricts cellular death of via oxidative stress. Besides that, some controversial results are also reported concerning oxidative stress; nanoceria either produce either pro-oxidative or antioxidant characteristics [75,76]. A few investigations have reported that nanoceria had antibacterial activity [77,78] .

Nanoceria cytotoxicity assay carried out using fibrosarcoma (HT- 1080) cells and breast cancer of human (MCF-7), no cellular death was found when the cells were treated with NPs at concentrations of 20, 50, 100 and 200 μg mL. The improvement of glutathione (GSH) production and the lowered depletion of GSH induced by hydrogen peroxide in the NPs treated cells was reported [79]. Targeted drug delivery is the most difficult task in neuroscience because the blood-brain barrier (BBB), inhibits the passage of large molecules as it works as a selective filter. *In vitro* and *in vivo* investigation affirmed that NPs were utilized as carriers to cross the blood-brain barrier [80]. The molecular process following nanoceria toxicity of the lung adenocarcinoma (A549) cells has been discussed. These NPs induced some morphological changes in A549 cells. It also leads to higher rates of cell apoptosis due to increased number of positive cells to annexin-V and decrease in mitochondrial membrane potential. These results were confirmed by changes in expression of BAX, Bcl-2, Cyt-C, AIF, caspase-3 and caspase-9 using immunoblot analysis, so reactive oxygen species caused DNA damage and cell cycle interception that caused apoptotic cell death in A549 cells following exposure to nanoceria [81].

Copper oxide nanoparticles

NPs of metal oxide, like copper oxide (CuO), have gained attention due to their antimicrobial and biocide qualities, and can be used in several biomedical purposes [82]. Copper oxide metal is semiconductor material of special mechanical, electrical and electromagnetic properties and has been used for various applications, such as fuel cells, near infrared detectors, electromagnetic storage media, sensors, catalysis, and semiconductor [83-85].

While CuO NPs (CuO NPs) have been shown to be used in medicinal purposes, the big alert for their use in the medical field is owing to their highly poisonous effects [86,87]. CuO NPS might be detrimental to mammalian cells, vertebrates and to invertebrates. The key mechanism of toxicity depends on the increased production of reactive oxygen species [88]. Such NPs therefore trigger oxidative stress in human epithelial pulmonary cells, facilitate toxicity and may cause serious damage to DNA and mitochondria [89].

CuO NPs are primarily used as antibacterial agents. These have been used in hospitals owing to their antibacterial ability when an acceptable dosage was used. Researchers also showed that the usage of CuO can decrease the prevalence of hospital-acquired diseases and therefore the costs of the health care sector. Bed sheets containing CuO NPs are recognized as important advances in healthcare, as they eliminate bacterial contact and therefore bacterial contaminants in hospitals [90].

A previous work has shown that CuO NPs now have therapeutic effects on the skin [91] especially when used in small quantities [92]. Another potential action of these nanomaterials relies on their role in wound healing. Multiple dressings of wound also textiles has been developed for treating burns as well as other skin lesions. The healing process has been shown to be specifically associated with the capability of CuO NPs to

reduce microbial colonization in the treated areas and to prevent infection, thus encouraging the regeneration of damaged tissue [93].

Carbon nanotubes and liposomes:

The physical and chemical properties of the carbon nanotubes (CNTs) have accelerated their usage in different scientific fields. Surface modification of these particulates and their functionalization with molecular biological molecules has broadened their use in nano biotechnology [94,95]. Due to their nanometer size, nanotubes could be beneficial to drug delivery vehicles, making them move easily within the body [12]. CNTs are promising platforms for bone and osteoblastic proliferation [96]. It has been shown that the unmodified single- and multi-walled toxicity of CNTs depends on concentration, these particles can be safely used in osteoblast cultures in lower concentrations [97]. The utilization of collagen-changed calcium carbonate nanotubes as another age of cylindrical structures for regeneration of bone has been reported [98]. Liposomes are synthetic vesicles from natural phospholipids with globular character. They serve as immunological adjuvants and drug carriers. Over the last two decades, liposomes have been greatly considered as a carrier for cancer medication, gene therapy and vaccines among other uses [99,100]. Both carbon nanotube and liposomes possess a huge potential for different biomedical applications especially in drug delivery yet remains understudied.

Conclusions

Through this review, it was shown that NPs and nanomaterials are already being as a widely researched field for different biomedical applications. Several NPs need proper investigation for possible use in biological applications. Drug delivery using NPs could be advantageous; there is therefore a need for further work in this field. The outcomes of exposure for certain type of nanoparticles depending on the route of administration, the dose and the physiochemical characteristics of such NP. The desired action of a therapeutic NP depends mainly on its ability to overcome a multitude of barriers to have the intended on-target, on-site effects.

References

[1] Thrall, J.H. (2004): Nanotechnology and medicine. Radiology, 230(2): 315-8.

[2] Whitesides, G.M. (2005): Nanoscience, nanotechnology, and chemistry. Small, 1(2): 172-9.

[3] Chan, W.C. and Nie, S. (1998): Quantum dot bioconjugates for ultrasensitive nonisotopic detection. Science, 281(5385): 2016-8.

[4] Vaseashta, A. and Dimova-Malinovska, D. (2005): Nanostructured and nanoscale devices, sensors and detectors. Sci Technol Adv Mater, 6(3-4): 312-8.

[5] Langer, R. (2001): Drugs on target. Science, 293(5527): 58-9.

[6] Roy, K.; Mao, H.-Q.; Huang, S.-K. and Leong, K.W. (1999): Oral gene delivery with chitosan–DNA nanoparticles generates immunologic protection in a murine model of peanut allergy. Nat. Med, 5(4): 387.

[7] Sachlos, E.; Gotora, D. and Czernuszka, J.T. (2006): Collagen scaffolds reinforced with biomimetic composite nano-sized carbonate-substituted hydroxyapatite crystals and shaped by rapid prototyping to contain internal microchannels. J. Tissue Eng, 12(9): 2479-87.

[8] Farokhzad, O.C.; Cheng, J.; Teply, B.A.; Sherifi, I.; Jon, S.; Kantoff, P.W.; Richie, J.P. and Langer, R. (2006): Targeted nanoparticle-aptamer bioconjugates for cancer chemotherapy in vivo. Proceedings of the National Academy of Sciences, 103(16): 6315-20.

[9] Morones, J.R.; Elechiguerra, J.L.; Camacho, A.; Holt, K.; Kouri, J.B.; Ramírez, J.T. and Yacaman, M.J. (2005): The bactericidal effect of silver nanoparticles. Nanotechnology, 16(10): 2346.

[10] Panáček, A.; Kvitek, L.; Prucek, R.; Kolář, M.; Večeřová, R.; Pizúrová, N.; Sharma, V.K.; Nevěčná, T.j. and Zbořil, R. (2006): Silver colloid nanoparticles: synthesis, characterization, and their antibacterial activity. J. Phys. Chem. B, 110(33): 16248-53.

[11] Saji, V.S.; Choe, H.C. and Yeung, K.W. (2010): Nanotechnology in biomedical applications: a review. Int. J. Nano Biomater, 3(2): 119-39.

[12] Faraji, A.H. and Wipf, P. (2009): Nanoparticles in cellular drug delivery. Bioorg. Med. Chem, 17(8): 2950-62.

[13] Liu, D.; Yang, F.; Xiong, F. and Gu, N. The smart drug delivery system and its clinical potential. Theranostics 6: 1306–1323. 2016.

[14] Castner, D.G. and Ratner, B.D. (2002): Biomedical surface science: Foundations to frontiers. Surf Sci, 500(1-3): 28-60.

[15] McNamara, L.E.; McMurray, R.J.; Biggs, M.J.; Kantawong, F.; Oreffo, R.O. and Dalby, M.J. (2010): Nanotopographical control of stem cell differentiation. J. Tissue Eng, 1(1): 120623.

[16] Yim, E.K.; Darling, E.M.; Kulangara, K.; Guilak, F. and Leong, K.W. (2010): Nanotopography-induced changes in focal adhesions, cytoskeletal organization, and mechanical properties of human mesenchymal stem cells. Biomaterials, 31(6): 1299-306.

[17] Menzies, K.L. and Jones, L. (2010): The impact of contact angle on the biocompatibility of biomaterials. Optom Vis Sci, 87(6): 387-99.

[18] Ramos, A.P.; Cruz, M.A.; Tovani, C.B. and Ciancaglini, P. (2017): Biomedical applications of nanotechnology. Biophys Rev, 9(2): 79-89.

[19] Nikolova, M.P. and Chavali, M.S. (2020): Metal Oxide Nanoparticles as Biomedical Materials. Biomimetics, 5(2): 27.

[20] Oh, J.; Feldman, M.D.; Kim, J.; Condit, C.; Emelianov, S. and Milner, T.E. (2006): Detection of magnetic nanoparticles in tissue using magneto-motive ultrasound. Nanotechnology, 17(16): 4183.

[21] Liu, H.; Zhang, J.; Chen, X.; Du, X.-S.; Zhang, J.-L.; Liu, G. and Zhang, W.-G. (2016): Application of iron oxide nanoparticles in glioma imaging and therapy: from bench to bedside. Nanoscale, 8(15): 7808-26.

[22] Hong, H.; Shi, J.; Yang, Y.; Zhang, Y.; Engle, J.W.; Nickles, R.J.; Wang, X. and Cai, W. (2011): Cancer-targeted optical imaging with fluorescent zinc oxide nanowires. Nano Lett, 11(9): 3744-50.

[23] Liu, T.-Y.; Liao, H.-C.; Lin, C.-C.; Hu, S.-H. and Chen, S.-Y. (2006): Biofunctional ZnO nanorod arrays grown on flexible substrates. Langmuir, 22(13): 5804-9.

[24] Yin, Z.F.; Wu, L.; Yang, H.G. and Su, Y.H. (2013): Recent progress in biomedical applications of titanium dioxide. Chem. Phys, 15(14): 4844-58.

[25] Hanawa, T. (2011): A comprehensive review of techniques for biofunctionalization of titanium. J Periodontal Implant Sci, 41(6): 263-72.

[26] Brammer, K.S.; Frandsen, C.J. and Jin, S. (2012): TiO2 nanotubes for bone regeneration. Trends Biotechnol, 30(6): 315-22.

[27] Özkurt, Z. and Kazazoğlu, E. (2011): Zirconia dental implants: a literature review. J Oral Implantol, 37(3): 367-76.

[28] Bhattacharya, R. and Mukherjee, P. (2008): Biological properties of "naked" metal nanoparticles. Adv. Drug Deliv. Rev, 60(11): 1289-306.

[29] Wang, H.; Huff, T.B.; Zweifel, D.A.; He, W.; Low, P.S.; Wei, A. and Cheng, J.-X. (2005): In vitro and in vivo two-photon luminescence imaging of single gold nanorods. Proceedings of the National Academy of Sciences, 102(44): 15752-6.

[30] Liao, H.; Nehl, C.L. and Hafner, J.H. (2006): Biomedical applications of plasmon resonant metal nanoparticles. Nanomedicine (Lond), 2: 201-8.

[31] Moyano, D.F. and Rotello, V.M. (2011): Nano meets biology: structure and function at the nanoparticle interface. Langmuir, 27(17): 10376-85.

[32] Tian, J.; Wong, K.K.; Ho, C.M.; Lok, C.N.; Yu, W.Y.; Che, C.M.; Chiu, J.F. and Tam, P.K. (2007): Topical delivery of silver nanoparticles promotes wound healing. ChemMedChem, 2(1): 129-36.

[33] Alt, V.; Bechert, T.; Steinrücke, P.; Wagener, M.; Seidel, P.; Dingeldein, E.;

Domann, E. and Schnettler, R. (2004): An in vitro assessment of the antibacterial properties and cytotoxicity of nanoparticulate silver bone cement. Biomaterials, 25(18): 4383-91.

[34] Guidelli, É.J.; Kinoshita, A.; Ramos, A.P. and Baffa, O. (2013): Silver nanoparticles delivery system based on natural rubber latex membranes. J Nanopart Res, 15(4): 1536.

[35] Abukabda, A.B.; Stapleton, P.A. and Nurkiewicz, T.R. (2016): Metal nanomaterial toxicity variations within the vascular system. Curr. Environ. health Rep, 3(4): 379-91.

[36] Wang, Z.L. (2008): Splendid one-dimensional nanostructures of zinc oxide: a new nanomaterial family for nanotechnology. ACS nano, 2(10): 1987-92.

[37] Yang, P.; Yan, R. and Fardy, M. (2010): Semiconductor nanowire: what's next? Nano lett, 10(5): 1529-36.

[38] Huang, M.H.; Wu, Y.; Feick, H.; Tran, N.; Weber, E. and Yang, P. (2001): Catalytic growth of zinc oxide nanowires by vapor transport. Adv. Mater, 13(2): 113-6.

[39] Lao, C.S.; Park, M.-C.; Kuang, Q.; Deng, Y.; Sood, A.K.; Polla, D.L. and Wang, Z.L. (2007): Giant enhancement in UV response of ZnO nanobelts by polymer surface-functionalization. J. Am. Chem. Soc, 129(40): 12096-7.

[40] Yakimova, R.; Selegård, L.; Khranovskyy, V.; Pearce, R.; Lloyd Spetz, A. and Uvdal, K. (2012): ZnO materials and surface tailoring for biosensing. Front Biosci (Elite Ed), 4(1): 254-78.

[41] Özgür, Ü.; Alivov, Y.I.; Liu, C.; Teke, A.; Reshchikov, M.; Doğan, S.; Avrutin, V.; Cho, S.-J. and Morkoç. (2005): A comprehensive review of ZnO materials and devices. J. Appl. Phys, 98(4): 11.

[42] Nohynek, G.; Dufour, E. and Roberts, M. (2008): Nanotechnology, cosmetics and the skin: is there a health risk? Skin Pharmacol Physiol, 21(3): 136-49.

[43] Nohynek, G.J.; Lademann, J.; Ribaud, C. and Roberts, M.S. (2007): Grey goo on the skin? Nanotechnology, cosmetic and sunscreen safety. Crit. Rev. Toxicol, 37(3): 251-77.

[44] Liu, D.; Wu, W.; Qiu, Y.; Yang, S.; Xiao, S.; Wang, Q.-Q.; Ding, L. and Wang, J. (2008): Surface functionalization of ZnO nanotetrapods with photoactive and electroactive organic monolayers. Langmuir, 24(9): 5052-9.

[45] Taratula, O.; Galoppini, E.; Wang, D.; Chu, D.; Zhang, Z.; Chen, H.; Saraf, G. and Lu, Y. (2006): Binding studies of molecular linkers to ZnO and MgZnO nanotip films. J. Phys. Chem. B, 110(13): 6506-15.

[46] Zhou, J.; Xu, N.S. and Wang, Z.L. (2006): Dissolving behavior and stability of ZnO wires in biofluids: a study on biodegradability and biocompatibility of ZnO nanostructures. Adv. Mater, 18(18): 2432-5.

[47] Zhang, Y.; Nayak, T.R.; Hong, H. and Cai, W. (2013): Biomedical applications of zinc oxide nanomaterials. Curr. Mol. Med, 13(10): 1633-45.

[48] Benn, T.M. and Westerhoff, P. (2008): Nanoparticle silver released into water from commercially available sock fabrics. Environ. Sci. Technol, 42(11): 4133-9.

[49] Ling, J.; Li, Y.F. and Huang, C.Z. (2009): Visual sandwich immunoassay system on the basis of plasmon resonance scattering signals of silver nanoparticles. Anal. Chem, 81(4): 1707-14.

[50] Chaudhry, Q.; Scotter, M.; Blackburn, J.; Ross, B.; Boxall, A.; Castle, L.; Aitken, R. and Watkins, R. (2008): Applications and implications of nanotechnologies for the food sector. Food Addit Contam, 25(3): 241-58.

[51] Nadworny, P.L.; Wang, J.; Tredget, E.E. and Burrell, R.E. (2008): Anti-inflammatory activity of nanocrystalline silver in a porcine contact dermatitis model. Nanomedicine, 4(3): 241-51.

[52] Wright, J.B.; Lam, K.; Buret, A.G.; Olson, M.E. and Burrell, R.E. (2002): Early healing events in a porcine model

of contaminated wounds: effects of nanocrystalline silver on matrix metalloproteinases, cell apoptosis, and healing. Wound Repair Regen, 10(3): 141-51.

[53] Huang, Y.; Li, X.; Liao, Z.; Zhang, G.; Liu, Q.; Tang, J.; Peng, Y.; Liu, X. and Luo, Q. (2007): A randomized comparative trial between Acticoat and SD-Ag in the treatment of residual burn wounds, including safety analysis. Burns, 33(2): 161-6.

[54] Sladkova, M.; Vlčková, B.; Pavel, I.; Šišková, K. and Šlouf, M. (2009): Surface-enhanced Raman scattering from a single molecularly bridged silver nanoparticle aggregate. J. Mol. Struct, 924: 567-70.

[55] Choi, O.; Deng, K.K.; Kim, N.-J.; Ross Jr, L.; Surampalli, R.Y. and Hu, Z. (2008): The inhibitory effects of silver nanoparticles, silver ions, and silver chloride colloids on microbial growth. Water Res, 42(12): 3066-74.

[56] Foldbjerg, R.; Olesen, P.; Hougaard, M.; Dang, D.A.; Hoffmann, H.J. and Autrup, H. (2009): PVP-coated silver nanoparticles and silver ions induce reactive oxygen species, apoptosis and necrosis in THP-1 monocytes. Toxicol. Lett, 190(2): 156-62.

[57] Davy, T. and Castellano, S. (2018): The genomics of selenium: Its past, present and future. Biochim Biophys Acta Gen Subj, 1862(11): 2427-32.

[58] Romero-Pérez, A.; García-García, E.; Zavaleta-Mancera, A.; Ramírez-Bribiesca, J.E.; Revilla-Vázquez, A.; Hernández-Calva, L.M.; López-Arellano, R. and Cruz-Monterrosa, R.G. (2010): Designing and evaluation of sodium selenite nanoparticles in vitro to improve selenium absorption in ruminants. Vet. Res. Commun, 34(1): 71-9.

[59] Fang, X.; Li, C.e.; Zheng, L.; Yang, F. and Chen, T. (2018): Dual-Targeted Selenium Nanoparticles for Synergistic Photothermal Therapy and Chemotherapy of Tumors. Chem Asian J, 13(8): 996-1004.

[60] Zhai, S.; Hu, X.; Hu, Y.; Wu, B. and Xing, D. (2017): Visible light-induced crosslinking and physiological stabilization of diselenide-rich nanoparticles for redox-responsive drug release and combination chemotherapy. Biomaterials, 121: 41-54.

[61] Hosnedlova, B.; Kepinska, M.; Skalickova, S.; Fernandez, C.; Ruttkay-Nedecky, B.; Peng, Q.; Baron, M.; Melcova, M.; Opatrilova, R.; Zidkova, J.; Bjørklund, G.; Sochor, J. and Kizek, R. (2018): Nano-selenium and its nanomedicine applications: a critical review. Int. J. Nanomedicine, 13: 2107-28.

[62] Korsvik, C.; Patil, S.; Seal, S. and Self, W.T. (2007): Superoxide dismutase mimetic properties exhibited by vacancy engineered ceria nanoparticles. ChemComm, (10): 1056-8.

[63] Dao, N.N.; Dai Luu, M.; Nguyen, Q.K. and Kim, B.S. (2011): UV absorption by cerium oxide nanoparticles/epoxy composite thin films. Advances in Natural Sciences: Nanoscience and Nanotechnology, 2(4): 045013.

[64] Zholobak, N.; Ivanov, V.; Shcherbakov, A.; Shaporev, A.; Polezhaeva, O.; Baranchikov, A.Y.; Spivak, N.Y. and Tretyakov, Y.D. (2011): UV-shielding property, photocatalytic activity and photocytotoxicity of ceria colloid solutions. J. Photochem. Photobiol. B, Biol, 102(1): 32-8.

[65] Trovarelli, A. (1996): Catalytic properties of ceria and CeO2-containing materials. Catal Rev Sci Eng, 38(4): 439-520.

[66] Wang, C.-H. and Lin, S.-S. (2004): Preparing an active cerium oxide catalyst for the catalytic incineration of aromatic hydrocarbons. Applied Catalysis A: General, 268(1-2): 227-33.

[67] Peng, L.; He, X.; Zhang, P.; Zhang, J.; Li, Y.; Zhang, J.; Ma, Y.; Ding, Y.; Wu, Z. and Chai, Z. (2014): Comparative pulmonary toxicity of two ceria nanoparticles with the same primary size. Int. J. Mol. Sci, 15(4): 6072-85.

[68] Pulido-Reyes, G.; Rodea-Palomares, I.; Das, S.; Sakthivel, T.S.; Leganes, F.;

Rosal, R.; Seal, S. and Fernández-Piñas, F. (2015): Untangling the biological effects of cerium oxide nanoparticles: the role of surface valence states. Sci. Rep, 5: 15613.

[69] Dahle, J.T. and Arai, Y. (2015): Environmental geochemistry of cerium: applications and toxicology of cerium oxide nanoparticles. Int. J. Environ. Res, 12(2): 1253-78.

[70] Culcasi, M.; Benameur, L.; Mercier, A.; Lucchesi, C.; Rahmouni, H.; Asteian, A.; Casano, G.; Botta, A.; Kovacic, H. and Pietri, S. (2012): EPR spin trapping evaluation of ROS production in human fibroblasts exposed to cerium oxide nanoparticles: evidence for NADPH oxidase and mitochondrial stimulation. Chem. Biol. Interact, 199(3): 161-76.

[71] Perez, J.M.; Asati, A.; Nath, S. and Kaittanis, C. (2008): Synthesis of biocompatible dextran-coated nanoceria with pH-dependent antioxidant properties. Small, 4(5): 552-6.

[72] Urner, M.; Schlicker, A.; Z'graggen, B.R.; Stepuk, A.; Booy, C.; Buehler, K.P.; Limbach, L.; Chmiel, C.; Stark, W.J. and Beck-Schimmer, B. (2014): Inflammatory response of lung macrophages and epithelial cells after exposure to redox active nanoparticles: effect of solubility and antioxidant treatment. Environ. Sci. Technol, 48(23): 13960-8.

[73] Franchi, L.P.; Manshian, B.B.; de Souza, T.A.; Soenen, S.J.; Matsubara, E.Y.; Rosolen, J.M. and Takahashi, C.S. (2015): Cyto-and genotoxic effects of metallic nanoparticles in untransformed human fibroblast. Toxicol In Vitro, 29(7): 1319-31.

[74] Pešić, M.; Podolski-Renić, A.; Stojković, S.; Matović, B.; Zmejkoski, D.; Kojić, V.; Bogdanović, G.; Pavićević, A.; Mojović, M. and Savić, A. (2015): Anti-cancer effects of cerium oxide nanoparticles and its intracellular redox activity. Chem. Biol. Interact, 232: 85-93.

[75] Lord, M.S.; Jung, M.; Teoh, W.Y.; Gunawan, C.; Vassie, J.A.; Amal, R. and Whitelock, J.M. (2012): Cellular uptake and reactive oxygen species modulation of cerium oxide nanoparticles in human monocyte cell line U937. Biomaterials, 33(31): 7915-24.

[76] Rosenkranz, P.; Fernández-Cruz, M.; Conde, E.; Ramírez-Fernández, M.; Flores, J.; Fernández, M. and Navas, J. (2012): Effects of cerium oxide nanoparticles to fish and mammalian cell lines: An assessment of cytotoxicity and methodology. Toxicol In Vitro, 26(6): 888-96.

[77] Ravishankar, T.N.; Ramakrishnappa, T.; Nagaraju, G. and Rajanaika, H. (2015): Synthesis and characterization of CeO2 nanoparticles via solution combustion method for photocatalytic and antibacterial activity studies. ChemistryOpen, 4(2): 146-54.

[78] dos Santos, C.C.L.; Farias, I.A.P.; dos Reis Albuquerque, A.d.J.; e Silva, P.M.d.F.; da Costa One, G.M. and Sampaio, F.C., editors. Antimicrobial activity of nano cerium oxide (IV) (CeO2) against Streptococcus mutans. BMC Proc. 2014; 8(Suppl 4): P48.

[79] Akhtar, M.J.; Ahamed, M.; Alhadlaq, H.A.; Khan, M.M. and Alrokayan, S.A. (2015): Glutathione replenishing potential of CeO2 nanoparticles in human breast and fibrosarcoma cells. J. Colloid Interface Sci, 453: 21-7.

[80] Rajeshkumar, S. and Naik, P. (2018): Synthesis and biomedical applications of cerium oxide nanoparticles–a review. J. Appl. Biotechnol. Rep, 17: 1-5.

[81] Mittal, S. and Pandey, A.K. (2014): Cerium oxide nanoparticles induced toxicity in human lung cells: role of ROS mediated DNA damage and apoptosis. BioMed Res. Int, 2014.

[82] Nations, S.; Long, M.; Wages, M.; Maul, J.D.; Theodorakis, C.W. and Cobb, G.P. (2015): Subchronic and chronic developmental effects of copper oxide (CuO) nanoparticles on Xenopus laevis. Chemosphere, 135: 166-74.

[83] Devi, A.B.; Moirangthem, D.S.; Talukdar, N.C.; Devi, M.D.; Singh, N.R. and Luwang, M.N. (2014): Novel synthesis and characterization of CuO

nanomaterials: Biological applications. Chin Chem Lett, 25(12): 1615-9.

[84] Khashan, K.S.; Sulaiman, G.M. and Abdulameer, F.A. (2016): Synthesis and antibacterial activity of CuO nanoparticles suspension induced by laser ablation in liquid. Arab J Sci Eng, 41(1): 301-10.

[85] Kayani, Z.N.; Umer, M.; Riaz, S. and Naseem, S. (2015): Characterization of Copper oxide nanoparticles fabricated by the Sol–Gel Method. J. Electron, 44(10): 3704-9.

[86] Ostaszewska, T.; Chojnacki, M.; Kamaszewski, M. and Sawosz-Chwalibóg, E. (2016): Histopathological effects of silver and copper nanoparticles on the epidermis, gills, and liver of Siberian sturgeon. Environ. Sci. Pollut. Res, 23(2): 1621-33.

[87] Perreault, F.; Melegari, S.P.; da Costa, C.H.; Rossetto, A.L.d.O.F.; Popovic, R. and Matias, W.G. (2012): Genotoxic effects of copper oxide nanoparticles in Neuro 2A cell cultures. Sci. Total Environ, 441: 117-24.

[88] Ruiz, P.; Katsumiti, A.; Nieto, J.A.; Bori, J.; Jimeno-Romero, A.; Reip, P.; Arostegui, I.; Orbea, A. and Cajaraville, M.P. (2015): Short-term effects on antioxidant enzymes and long-term genotoxic and carcinogenic potential of CuO nanoparticles compared to bulk CuO and ionic copper in mussels Mytilus galloprovincialis. Mar. Environ. Res, 111: 107-20.

[89] Sankar, R.; Maheswari, R.; Karthik, S.; Shivashangari, K.S. and Ravikumar, V. (2014): Anticancer activity of Ficus religiosa engineered copper oxide nanoparticles. Mater. Sci. Eng. C, 44: 234-9.

[90] Lazary, A.; Weinberg, I.; Vatine, J.-J.; Jefidoff, A.; Bardenstein, R.; Borkow, G. and Ohana, N. (2014): Reduction of healthcare-associated infections in a long-term care brain injury ward by replacing regular linens with biocidal copper oxide impregnated linens. J. Infect. Dis, 24: 23-9.

[91] Dykes, P. (2015): Increase in skin surface elasticity in normal volunteer subjects following the use of copper oxide impregnated socks. Skin Res Technol, 21(3): 272-7.

[92] Borkow, G. and Gabbay, J. (2008): Biocidal textiles can help fight nosocomial infections. Med. Hypotheses, 70(5): 990-4.

[93] Grigore, M.E.; Biscu, E.R.; Holban, A.M.; Gestal, M.C. and Grumezescu, A.M. (2016): Methods of synthesis, properties and biomedical applications of CuO nanoparticles. Pharmaceuticals, 9(4): 75.

[94] Sharma, P.; Kumar Mehra, N.; Jain, K. and Jain, N. (2016): Biomedical applications of carbon nanotubes: a critical review. Curr Drug Deliv, 13(6): 796-817.

[95] Williams, K.A.; Veenhuizen, P.T.; Beatriz, G.; Eritja, R. and Dekker, C. (2002): Nanotechnology: carbon nanotubes with DNA recognition. Nature, 420(6917): 761.

[96] Yoon, I.-K.; Hwang, J.-Y.; Jang, W.-C.; Kim, H.-W. and Shin, U.S. (2014): Natural bone-like biomimetic surface modification of titanium. Appl. Surf. Sci, 301: 401-9.

[97] Zancanela, D.C.; de Faria, A.N.; Simão, A.M.S.; Gonçalves, R.R.; Ramos, A.P. and Ciancaglini, P. (2016): Multi and single walled carbon nanotubes: effects on cell responses and biomineralization of osteoblasts cultures. J Mater Sci Mater Med, 27(3): 62.

[98] Tovani, C.; Zancanela, D.; Faria, A.; Ciancaglini, P. and Ramos, A. (2016): Bio-inspired synthesis of hybrid tube-like structures based on CaCO 3 and type I-collagen. RSC Adv, 6(93): 90509-15.

[99] Liu, Y. and Chen, C. (2016): Role of nanotechnology in HIV/AIDS vaccine development. Adv. Drug Deliv. Rev, 103: 76-89.

[100] Ghalandarlaki, N.; Alizadeh, A.M. and Ashkani-Esfahani, S. (2014): Nanotechnology-applied curcumin for different diseases therapy. BioMed Res. Int, 2014.

[101] Khorrami, M.B.; Sadeghnia, H.R.; Pasdar, A.; Ghayour-Mobarhan, M.; Riahi-Zanjani, B.; Hashemzadeh, A.; Zare, M. and Darroudi, M. (2019): Antioxidant and toxicity studies of biosynthesized cerium oxide nanoparticles in rats. Int. J. Nanomedicine, 14: 2915.

[102] Kumari, M.; Kumari, S.I. and Grover, P. (2014): Genotoxicity analysis of cerium oxide micro and nanoparticles in Wistar rats after 28 days of repeated oral administration. Mutagenesis, 29(6): 467-79.

[103] Ma, J.Y.; Mercer, R.R.; Barger, M.; Schwegler-Berry, D.; Scabilloni, J.; Ma, J.K. and Castranova, V. (2012): Induction of pulmonary fibrosis by cerium oxide nanoparticles. Toxicol. Appl. Pharmacol, 262(3): 255-64.

[104] Reddy, A. (2018): Copper Oxide Nanoparticles Induces Oxidative Stress and Liver toxicity in Rats following Oral Exposure. Toxicol. Rep, 5.

[105] Tang, H.; Xu, M.; Luo, J.; Zhao, L.; Ye, G.; Shi, F.; Lv, C.; Chen, H.; Wang, Y. and Li, Y. (2019): Liver toxicity assessments in rats following sub-chronic oral exposure to copper nanoparticles. Environ. Sci. Eur, 31(1): 30.

[106] Elsharkawy, E.E.; El-Nasser, M.A. and Kamaly, H.F. (2019): Silver nanoparticles testicular toxicity in rat. Environ. Toxicol. Pharmacol, 70: 103194.

[107] Wen, H.; Dan, M.; Yang, Y.; Lyu, J.; Shao, A.; Cheng, X.; Chen, L. and Xu, L. (2017): Acute toxicity and genotoxicity of silver nanoparticle in rats. PLoS One, 12(9).

[108] Hassanen, E.I.; Khalaf, A.A.; Tohamy, A.F.; Mohammed, E.R. and Farroh, K.Y. (2019): Toxicopathological and immunological studies on different concentrations of chitosan-coated silver nanoparticles in rats. Int. J. Nanomedicine, 14: 4723.

[109] Sardari, R.R.R.; Zarchi, S.R.; Talebi, A.; Nasri, S.; Imani, S.; Khoradmehr, A. and Sheshde, S.A.R. (2012): Toxicological effects of silver nanoparticles in rats. Afr J Microbiol Res, 6(27): 5587-93.

[110] Sung, J.H.; Ji, J.H.; Yoon, J.U.; Kim, D.S.; Song, M.Y.; Jeong, J.; Han, B.S.; Han, J.H.; Chung, Y.H. and Kim, J. (2008): Lung function changes in Sprague-Dawley rats after prolonged inhalation exposure to silver nanoparticles. Inhal Toxicol, 20(6): 567-74.

[111] Trickler, W.J.; Lantz, S.M.; Murdock, R.C.; Schrand, A.M.; Robinson, B.L.; Newport, G.D.; Schlager, J.J.; Oldenburg, S.J.; Paule, M.G. and Slikker Jr, W. (2010): Silver nanoparticle induced blood-brain barrier inflammation and increased permeability in primary rat brain microvessel endothelial cells. Toxicol. Sci, 118(1): 160-70.

[112] Stensberg, M.C.; Wei, Q.; McLamore, E.S.; Porterfield, D.M.; Wei, A. and Sepúlveda, M.S. (2011): Toxicological studies on silver nanoparticles: challenges and opportunities in assessment, monitoring and imaging. Nanomedicine, 6(5): 879-98.

[113] Abbasalipourkabir, R.; moradi-sardareh, H.; Zarei, S.; Asadi, S.; Salehzadeh, A.; Ghafourikhosroshahi, A. and Ziamajidi, N. (2015): Toxicity of zinc oxide nanoparticles on adult male Wistar rats. Food Chem. Toxicol, 84.

[114] Park, H.-S.; Kim, S.-J.; Lee, T.-J.; Kim, G.-Y.; Meang, E.; Hong, J.-S.; Kim, S.-H.; Koh, S.-B.; Hong, S.-G. and Sun, Y.-S. (2014): A 90-day study of sub-chronic oral toxicity of 20 nm positively charged zinc oxide nanoparticles in Sprague Dawley rats. Int. J. Nanomedicine, 9(Suppl 2): 93.

[115] Jeng, H.A. and Swanson, J. (2006): Toxicity of metal oxide nanoparticles in mammalian cells. J. Environ. Sci and Health Part A, 41(12): 2699-711.

[116] Guan, R.; Kang, T.; Lu, F.; Zhang, Z.; Shen, H. and Liu, M. (2012): Cytotoxicity, oxidative stress, and genotoxicity in human hepatocyte and embryonic kidney cells exposed to ZnO nanoparticles. Nanoscale Res. Lett, 7(1): 602.

[117] He, Y.; Chen, S.; Liu, Z.; Cheng, C.; Li, H. and Wang, M. (2014): Toxicity of selenium nanoparticles in male Sprague–Dawley rats at supranutritional and nonlethal levels. Life Sci, 115(1-2): 44-51.

[118] Dal Bosco, L.; Weber, G.E.; Parfitt, G.M.; Paese, K.; Gonçalves, C.O.; Serodre, T.M.; Furtado, C.A.; Santos, A.P.; Monserrat, J.M. and Barros, D.M. (2015): PEGylated carbon nanotubes impair retrieval of contextual fear memory and alter oxidative stress parameters in the rat hippocampus. BioMed Res. Int, 2015.

[119] Zhang, L.W.; Zeng, L.; Barron, A.R. and Monteiro-Riviere, N.A. (2007): Biological interactions of functionalized single-wall carbon nanotubes in human epidermal keratinocytes. Int. J. Toxicol, 26(2): 103-13.

[120] Shang, S.; Yang, S.-Y.; Liu, Z.-M. and Yang, X. (2015): Oxidative damage in the kidney and brain of mice induced by different nano-materials. Front Biol (Beijing), 10(1): 91-6.

الملخص العربي

بعض التأثيرات البيولوجية والطبية الحيوية للجسيمات النانوية

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خلال العقد الماضي ، أدى التحسن الهائل في التكنولوجيا الحيوية النانوية وإنتاج المواد النانوية إلى الحصول على أشكال مختلفة من الجسيمات النانوية (**NPs**) ذات إمكانات هائلة متاحه للتطبيقات المتعلقة بالصحة التي لا تزال غير مدروسة. تمتد مثل هذه التطبيقات إلى ما هو أبعد من التأثير البشري المباشر من خلال التأثير على الظروف البيئية والإنتاج الحيواني وحتى منع تفشي أمراض معينة. من الواضح أن النمو المتزايد في إنتاج هذه المواد النانوية بالاضافه الي الآثار / الإمكانات غير المدروسة على صحة الإنسان يمثل أحد الآثار الجانبية الرئيسية. لا تشمل هذه القيود التوزيع الحيوي المحدد بالكامل والتأثيرات الفسيولوجية / السمية على أعضاء الجسم المختلفة بالإضافة إلى النشاط الخلوي عند التعرض. الجسيمات النانوية صغيرة جدًا في الحجم (من 1 إلى 100 نانومتر) وتوجد بأشكال مختلفة. هناك تصنيفات مختلفة للجسيمات النانوية حسب حجمها وشكلها وخصائصها. الجسيمات النانوية لها خصائص فيزيائية وكيميائية خاصة نتيجة لامتلاك مساحة سطح كبيرة وحجم نانوي. يمثل الافتقار إلى دراسات تقييم السلامة المناسبة لمثل هذه الجسيمات النانوية ، سواء في المختبر أو في الجسم الحي ، فضلاً عن النقص في التوزيع الحيوي / الآثار الضارة والآليات مصدر قلق كبير. نحاول فى هذه الدراسة الموجزة تحديد وربط التقارير حول العديد من الجسيمات النانوية وتطبيقها في الطب والبيولوجيا بالإضافة إلى تلخيص أي اختلافات في الظروف التجريبية ، والسمية ، والأخطار البيولوجية ، وسلامة الجسيمات النانوية في الأعضاء المختلفة.