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NANOTECHNOLOGY IN FORENSIC SCIENCE: SCOPE AND CHALLENGES

Jagriti [1], Dr. Anil Kumar Jaiswal [2] and Dr. Ashok Kumar Jaiswal [3]

[1]. University of Delhi, New Delhi.
[2]. Assistant Professor, Department of Mathematics, St.Andrew's PG College, Gorakhpur, UP.
[3]. Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, New Delhi-110029

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ABSTRACT: Nanochemistry has gained importance in different fields since its advent in 1990's. One can find nanomaterials being used successfully in various fields such as engineering, medical, biochemistry, medicines etc. Forensic science too is not untouched by this emerging technology. Many reviews have been given regarding scope of nanotechnology in various fields such as biomedicine, medical, software industry, engineering etc. Many debates have been raised with respect to toxicity of nanomaterials and the present scenario calls for research in the area of maintaining nanotechnology sustainable as well as evolving. Here we will review the scope of nanomaterials in forensic science, their present applications , its future scope in the field of forensic science and the challenges that lay ahead.

KEYWORDS: Nanomaterials, Nanotechnology, Forensic science.

INTRODUCTION :

Nanoscience has emerged as the new promising technology with its applications sought in different fields. One can find new disciplinary sciences coined in terms of nanoscience such as nano0chemistry, nanophysics, nano23211.forensics and nanoelectronics. Nanomaterials have sought their ways in all natural and interdisciplinary sciences at a record speed. Their beauty does not lie only in their nano scales, though size does matters here a lot, but also in the unique properties that nanomaterials display due to their very small sizes.

Richard Feynman had introduced nano science in his famous lecture saying "there is plenty of room at the bottom" [1]. Nanotechnology has by far remained true to this statement as is evident from the emerging applications. There have been plethora of research attempts to use thermally, optically and electrically active nanomaterials in myriad fields. There are nanomaterials based chips, motors, electronic devices, medical instruments, drug delivery systems, inks, and what not [2-8]. A lot many reviews have been written on nanometrials and their uses in different fields [9-13]. The basic step to start with the nanomaterials is their characterization. It helps in better understanding of their properties and assessing their applicability. Several techniques are deployed to fabricate

Corresponding Author:
Dr. Ashok Kumar Jaiswal
Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, New Delhi-29

the nanostrutures. These include Scanning Electron Microscopy & Transmission Electron Microscopy [14-15], Atomic Force Microscopy [16-18], Dynamic Light Scattering [19-23] and Raman micro spectroscopy [24-26].

Forensic science has evolved a lot from nineteenth century to what we see today. It has become an integral part of criminal investigation and has become crucial in deriving a verdict in most of the cases. Forensic science has its own tools and mechanisms through which it aids the investigations. These include Latent fingerprint development, DNA sequencing, Questioned Document Analysis, Detection of explosives etc. Nanomaterials have been conjugated with all these mechanisms and have proved their superiority over the traditional methods. In this review, we will probe these mechanisms individually to find the utility of nanomaterials and the ways in which they improve the forensic analysis .

CURRENT UTILITY OF NANO-TECHNOLOGY IN FORENSIC SCIENCE:

a.) In Latent fingerprint development

Fingerprint development has constantly been a very reliable source of analysis and investigation in forensic science in order to solve a crime scene. Despite the advances made by other techniques, fingerprint analysis remains an assured tool for deciphering important facts and clues in a criminal case. Fingerprint of a person consists of definite ridge patterns which are unique to every individual. Finger marks are mixture of natural secretions from glands present on fingers. These include eccrine, epocrine and sebaceous. When any surface is touched by bare hands, it is bound to have his finger marks. These marks may be visible or latent. Visible fingerprints are obtained by the fingers marked with any ink while latent fingerprints are mostly invisible [27]. The detection of finger marks is achieved by several methods. These include optical methods viz luminescence or UV absorption; physical methods viz vacuum metal deposition or powdering ; chemical/physical methods viz. single metal deposition or multi metal deposition and chemical methods viz. metal composition or ninhydrin treatment [28-35]. The surfaces on which fingermarks are left play a critical role in the analysis. These surfaces may be porous, semi porous, non-porous, wet (with bloodstains or other fluids), or even of adhesive nature. Functionalized nanoparticles and TiO_2 nanoparticles have been proposed to obtain latent fingermarks on porous and non porous surfaces, wet with blood, or on the adhesive side of tapes [36-38]. Gold nanoparticles being inert in nature proves to be an ideal adsorbate surface for fingerprint development. Nanoparticles are reported to enhance the fingerprints and increase the contrasts of the finger marks from that of the background . Nanoparticles other than gold deployed in latent finger mark detection are titanium oxide, zinc oxide, iron oxide, europium oxide, molybdenum disulfide, CdS, CdSe and noble metals nanocrystals [39-42]. Powdered form of nanoparticles of gold , silver , europium and yetterbium have been reported to be used in developing latent fingermarks on porous and non porous surfaces. Fingermarks on the adhesive side of black electrical tape and those with bloody prints on porous and semi porous surfaces have been developed using titanium dioxide powder [43-46]. To make the procedure for latent fingermarks development faster and easier, D.Gao et. al. [47] proposed a one-step single-metal nanoparticles deposition method (SND) technique producing sharp and clear development of latent fingermarks in a wide pH range. Antibody–gold nanoparticle conjugates have been reported for the detection of the major metabolite of nicotine (cotinine) deposited in the sweat of latent fingerprints of the smokers [48]. Similar report has been given by Worley et. al. [49] regarding detection of inorganic componants in latent finger marks using micro X-ray flourescence (MXRF). Finger marks consists of secretions and these secretions may contain inorganic substrates. In most of the cases, the analysis of these secretions can give important clues about the person. The inorganic components include elements like potassium, flourine, calcium and aluminium which are generally used in lotions, gun powder. This gives possible clues about certain specific eating or addiction habits of accused and may prove a major resource in child trafficking. Drug users are more prone to criminal activities and the reports from Kun Li et. al. of detection of cocaine from the fingerprint analysis is sure to facilitate solving any case [50]. In order to avoid loosing any portion of latent finger marks which generally escapes due to variation in sweat composition between individuals, Nimer J et. al. have tried to reverse the conventional procedure by using paper as the substrate for developing finger marks with gold nanoparticles (AuNPs) in conjugation with bifunctional reagent and silver physical developer (Ag-PD) [51].

b.) Forensic Toxicology

It has been rightly said by famous Swiss scientist, Paracelsus, "Poison is in everything, and no- thing is without poison. The dosage makes it either a poison or a remedy."

A forensic toxicologist deals with the identification, estimation, analysis and possible interpretation of poisonous substances. These interpretations might be produced in court or for administrative purpose. Sources of poison may vary from industries, agriculture or horticulture, drugs, medication, food and eatables to variety of chemicals used in domestic households such as pesticides or toilet cleaners [52]. The samples to be analyzed for any kind of poisoning could be a tissue, hairs or some body fluids like blood, urine, vitreous humor, bile, or gastric contents obtained either during autopsy in case if the victim is already dead or they can be from a living person as well [53,54]. Forensic toxicology also involves the detection of alcohols, narcotics and other hallucinating drugs from the sample. We have discussed the detection of these drugs under the heading- Illicit Drug Detection. A rapid method to detect drugs in human urine has been proposed by Ronglu Dong et. al. using dynamic surface-enhanced Raman spectroscopy (D-SERS) and gold nanorods (GNRs) and a classification algorithm called support vector machines (SVM) [55]. A colorimetric sulfide sensor based on gold nanoparticles (AuNP) modified calix[n]arene assembly has been designed by A. Pandya et. al. for the determination of sulfide in spiked water and leather waste water [56].

c.) Illicit Drug Detection

Doping among athletes and sportspersons has become more frequent with the continuous and incessant surfacing of new designer drugs in the market [57]. It is now imperative to get equipped with a rapid and sensitive detection system with a wide range of applicability. Detection of drugs like cocaine, heroin and other barbituric alkaloids has been accomplished by methods like chemical colour test, gas chromatography with UV or MS detectors and gas-liquid chromatography [58]. Recent advances in this field includes use of capillary electrophoresis, nano-gold, nano-silver and nano sized particles of titatinium dioxide (TiO_2) coupled with SEM, TEM and FTIR [59]. Functionalized magnetic particles with antibodies have been used by Hazarika et. al. for the detection of a range of drugs and drug metabolites like D 9 - tetrahydrocannabinol (found in marijuana), methadone (a synthetic opioid), 2-ethylidene-1,5-dimethyl-3,3, diphenylpyrrolidine (EDDP) (metabolite of methadone) and benzoylecgonine (metabolite of cocaine), and morphine (metabolite of heroin) deposited within latent fingerprints [60-61]. Andreou et. al. reported a microfluidic system using silver nanoparticles which can detect drugs of abuse in saliva [62]. Similarily, gold nanoparticles have been functionalized with charged polymers by Zhang et. al. and used with CE-MS to assess the impurities of an unclear illicit heroin sample and trace its geographical source [63]. Surface enhanced Raman scattering (SERS) has been an assuring tool for identification of drugs. Detection of drugs in human urine is complicated due to its low molecular affinity for metal surface and inefficient use of hotspots in one- or two-dimensional (2D) geometries. et. al. developed a strategy for separating amphetamines from human urine with an oil-in-water emulsion and monodisperse Ag nanoparticles to create three-dimensional (3D) SERS hotspots and thereby giving an estimate of Raman enhancement factor larger than 10^7 [64]. In SERS, Raman spectra are dramatically increased when a molecule is adsorbed onto nanoroughened noble metal surfaces such as silver and gold [65]. et. al. have come up with a “smart” system for the rapid detection and quantification of codeine sulphate using a smartphone. This system allows for ultrasensitive nanoaggregation colorimetric detection using citrate-stabilized gold nanoparticles (AuNPs) as a probe [66].

d.) Questioned Documents

A questioned document in forensic science is any document presented as an evidence in a criminal case. It includes extortion notes, ransom notes, or it may be any letter involved in the case. Wills, contracts, medical reports, writings on the wall at the crime scene or on body of the victim are also included as questioned documents. A forensic examiner employs varied methods from manual handwriting analysis to technologies as atomic force microscopy to analyse the questioned documents [67]. In case of forged bank notes or any documents where ink is involved, the minute analysis of inks may provide several hints. The major concern beneath analysis of question document is to examine the document with non/ minimal destruction. Nananostructured materials based on metals, silicon and carbon have been developed to assist mass spectroscopy in surface assisted laser desorption ionisation mass spectroscopy. Tang et al have worked on solvent free gold nanoparticles assisted laser desorption/ ionisation mass spectroscopy techniques to detect image inks and visible dyes on bank notes and questioned documents and analysed printing orders of different inks, forged writing/ alterations.[68] . Lim et. al. in their report, have discussed the role of specifically modified silicon and carbon based nanomaterials and how when coupled with mass spectrometry, they can improve the detection sensitivity, specificity, flexibility and reproducibility of SALDI-MS analysis [69].

e.) Detection of Explosives

Explosive based weapons form major component in most of the crime scenes. With easy availability and deplorability, they can cause high damages. With the advent of terrorism, the present scenario requires sensitive and accurate detection of explosives. The challenges involved in their detection are to maintain low vapor pressure and to update the techniques for detection of new explosive materials. The detection process primarily involves collection of trace elements as vapor or particulate samples and then their analysis with a sensitive sensor system. Current techniques of detection utilize mass spectroscopy, gas liquid chromatography (GLC), sensors, amplifying fluorescence polymers (AFP) and similar methodologies most of which turn out as cumbersome and tedious. Requirement of high degree of sensitivity and selectivity with low limit of detection (LOD) comes as the biggest challenge. An efficient explosive sensor is tuned to be reversible at room temperature and should have fast detection and regeneration time. It is difficult to incorporate all these characteristics in any single device or methodology. Nanomaterials have offered a respite by enhancing the sensitivity of molecular adsorption on their surfaces and being cost effective at the same time [70]. Trinitrotoluene (TNT) is the common explosive material used in most of the terror attacks and military exercises and hence has been extensively researched upon. A highly cost effective way of detecting trace TNT by the use of curcumin which is suggested as nanocurcumin by many biomedical studies, has been reported by A. Pandya et.al. [71]. Dasary *et. al.* , in their works, have utilized the Meisenheimer complex formed by cystein conjugated gold nanoparticles with trinitrotoluene (TNT) to enhance the signals in surface enhanced Raman spectroscopy (SERS) by manifold [72]. The same group has demonstrated that trace amount of TNT can be recognized using dynamic light scattering (DLS) probe paired with para-aminothiophenol (p-ATP) modified gold nanoparticle [73]. Single-walled silicon and carbon nanotubes (SWCN) with interdigited electrode capacitor have been reported for improved sensitivity in detection of TNT, heavy metal ions, hydrogen and CO_2 vapors [74-79]. Surface enhanced raman spectroscopy (SERS) has been an ideal choice due its non destructive nature and large Raman enhancement factor for detection of explosive materials. SERS , when combined with a robust substrate capable of giving high signal enhancements, can be a sensitive platform for detection of nitrobased explosives [80]. The group of Pedro et. al. have reported that commercial laboratory filter paper (Whatman filter paper grade 1) deposited with gold nanoparticles using thermal inkjet technology, can be used as an extremely low cost substrate for SERS [81]. There have been attempts to pair SERS with molecularly imprinted polymers (MIPs) to increase its robustness, selectivity, specifivity, cost effectiveness and real time on the spot detection of various explosives [82]. Besides SERS, fluorescence-quenching is another sensitive and convenient method widely used in explosives identification [83]. Naddo et. al. have reported a sensing nanofibril film fabricated from the alkoxycarbonyl-substituted, carbazole-cornered, arylene-ethynylene tetracycle (ACTC) where they exploit the electron donating power of the carbarazole to increase the efficiency of fluorescence quenching [84]. Flourescence quenching gets remarkably affected by shape, size and porosity of the sensing material. Large number of pores and their smaller diameters increase the quenching. S.Tao et. al. have utilized this fact by using porphyrin doped silica nanocomposite fibers fabricated by the electrospinning technique and sol–gel process for enhanced sensitivity towards TNT recognition [85].

f.) Electronic Nose

The idea of electronic nose (E-nose) has originated from human olfactory system. E-nose is basically a sensor device. In any

sensor, the surface chemical processes are transformed as signals. In case of E-nose, the signals are nothing but the unique odors particular of specific chemical reactions. Electronic nose consists of an “odor” sensor, a data preprocessor, and pattern recognition (PARC) engine [86]. Wilson. A.D. in his review has mentioned E-nose as the manifestation of electronic aroma detection (EAD) technologies [87]. Recent work have tried to fabricate the e-nose device using metal oxide ,metal oxide semiconducting (MOS), quartz crystal microbalance (QMB) and conducting polymers (CP) [88-91]. Due to their wide range of sensing, e-nose devices have been employed for environment monitoring to detect hazardous componants of industrial waste and sanitation wastes in air, water and soil. They are also used in recognition of heavy metal toxins, explosives, fire arm residues, non-fire-arm residues and pigmets in paints, all of which are generally collected as common evidences in forensics. The devices can also be used to detect human smells and the smell of drugs (medicinal and drugs of abuse) in the victim or in the culprit. Of late, along with thermal and optical, chemical sensing properties of nanostructured materials have been investigated. Compounds known for their chemical sensing abilities have been examined in their nanostructures for any difference. Q.H.Li et. al. have demonstrated increased oxygen sensing capability of ZnO when used as ZnO nanowire transistors [92]. In a similar attempt, single 1-D nanowire of semi-conducting metal oxides such as In_2O_3, have been developed to sense NH_3 and NO_2 at room temperature [93]. Nanostructures have helped overcome the limitation of very thin films and requirement of high temperatures for functioning of such semi conducting metal oxides. Chen et. al. have reviewed 1-D metal-oxide nanostructures and their role in development of chemical sensors and nanowires [94]. In an attempt to increase the sensitivity, selectivity, robustness, and real time on-the-spot detection of multiple gases, Chen et al. have come up with a new template built with four different semiconducting nanostructured materials, including In_2O_3 nanowires, SnO_2 nanowires, ZnO nanowires, and single- walled carbon nanotubes (SWNT) [95]. Sensors based on metal-oxides have been studied in nanostructured form. Elisabeth Comini has noted in her review on nanocrystals based gas sensors that high degree of crystalline and atomic sharp terminations make these crystals a promising platform for development of a new generation of FET based and optical based gas sensors [96]. The study of SnO_2 nanobelts by Comini et. al.
has demonstrated that sensor response to gases like CO and NO_2 and ethanol increases dramatically with the density of nanobelt [97]. Another study on SnO_2 based sensors indicate that SnO_2 nanobelts when functionalized with palladium and silver nanocrystals further improves the sensor’s selectivity and sensitivity towards carbon mono-oxide, hydrogen and oxygen gases [98-100].

g.) DNA Analysis

DNA analysis has experienced perhaps the fastest technological revolution since Human Genome Project. DNA analysis can be done in number of ways viz Y-chromosome analysis, short tandem repeat analysis (STR), mitochondrial DNA analysis. Polymerase Chain Reaction (PCR) is an important technique used with STR DNA analysis. The basic process of analysis can be summed up in three parts i) DNA extraction from the sample, ii) quantification, amplification using PCRs and iii) gel/capillary electrophoresis. The traditional techniques to extract DNA from urine, blood or semen invloves centrifugation or filtration which are quite labor intensive and time consuming processes . In general a complete DNA analysis may take a full day or two. The research efforts in this area focus on enhancing accuracy as well as making the process rapid [101,102]. Another limitation lying here is that the chances of sample getting contaminated is usually high while the scope of automation remains very bleak. Y. Lin et. al. have noted in their review that nanostructures and nanomaterials based DNA sensing can help the detection mechanism in moving beyond the unautomated and tedious conventional processes involving seiving and transient mechanisms without compromising sensitivity and selectivity of DNA sensors [103]. Bruce McCord has argued that nanotechnology can help in the development of microfluidic systems used in post PCR quantification process and can aid in integration of PCR amplification, seperation and detection in a single step [104]. Gold has been particularly focussed in its different structured forms such as nanobeads and nanoshells, to assist the DNA analysis procedure. Gold Nano shells have an advantage of open surface topology than closed topology of nano-aggregates or dimers and is preferable as SERS substrate. Barhoumi et al. have reported that as compared to randomly uncoiled DNA, adsorbtion of thermally uncoiled ssDNA and hybridized dsDNA result in more ordered monolayer adsobtion on gold nanoshell substrate with increased packing density thereby enhancing the uniformity and reproducibility of the SERS signals [105]. Intercalated gold nanoparticles as universal labels for the detection of double-stranded DNA has been reported to reduce the total time of detection process and is cost effective as compared to functionalized polymeric sysytem utilized in DNA analysis [106]. Nanomaterials have been introduced in polymerase chain reaction (PCR) owing to their high stablity, water-solublity and biocompatiblity plus their higher surface-area/volume ratios [107]. Gold nanoparticle have also attributed to increase in specificity and sensitivity as compared to both, conventional PCR and real time PCR [108]. Electrode surfaces with AuNPs aggregate have been studied in DNA detection but suffer in terms of selectivity and stability. In an effort to develop a stable DNA biosensor, G.Li et. al. have tried to use gold nanoparticles with polyamidoamine (PAMAM) dendrimer as the sensor probe and demonstrated that dendrimer and AuNPs based sensor exhibited a high selectivity, sensitivity and stability for the measurement of DNA hybridization [109]. H. Dong et. al. went a further step to develop a triplex signal amplification strategy in electrochemical detection and differentiation of DNA by assembling probe labeled gold nanoparticles (ssDNA-AuNP) on electrochemically reduced graphene oxide (ERGO) modified electrode with thiol group tagged DNA strand coupled with funtionalised carbon sphere as tracer [110]. Carbon nanotubes are another intensively research nanomaterials for DNA analysis used especially for fabrication of screen printed electrode to improve selectivity. A recent work by Huska et. al. used the carbon nanotube based screen printed electrode coupled offline with gel electrophoresis and reported a better responsivity towards detection of PCR ready DNA sample than those of carbon screen printed electrode. Their work attempted coupling of seperation and detection systems and to miniaturise the electrochemical detector system [111]. Nanomaterials display an extraordinarily high quenching ability and this property has propelled investigation in using then in fluorescence DNA analysis. Li and group in their study of nanoquenching effects of nanomaterials in different dimensions have shown that nanoquenching abilities of nanomaterials depend on their dimensionality. In a comparative study of AuNPs (0D), SWNTs (1D) and graphene oxide (GO) (2D), Li et. al. concluded that GO based sensor is better than AuNPs and SWNTs in differentiating ssDNA and dsDNA [112]. Magnetic nanoparticles can form stable complexes with blood, saliva and bacterial culture. This property has been exploited by X.Xie et. al. in extraction of genomic DNA from saliva and blood where they achieved simultaneous enrichment of target cells and adsorption of DNA on functionally modified magnetic nanobeads [113-115]. Study done by Z.Shan *et. al.* utilising carboxyl group modified magnetic nanoparticles (CMNPs) as solid phase adsorbent for urine genomic DNA extraction promises to be a simple, rapid, sensitive and environment friendly approach which can not only be followed easily in routine laboratory uses, but also opens a way for automated urine extraction system [116]. In an another study, Z. Shan et. al. reported that use of multifunctional carboxylated magnetic nanoparticles for E.coli bacteria capture, lysate clearance and plasmid DNA extraction requires less time than other conventional methods and costs less than expensive immunomagnetic paarticle [117] .

NANOTOXICITY- CHALLENGE TO MEET:

Naturally occuring nanoparticles have been present in our atmosphere in the form of dust, volcanic ash, forest fires, erosions etc. These generally constitute the particulate matter component of air. Particulate matter is conventionally characterized by its mass concentration, either as PM 10 or PM 2.5 They may be either micro or ultra fine particles (<100nm) and are a major source of air, water and soil pollution. Anthropogenic activities have aided the percentage of these particles in atmosphere via cooking, chemical manufacturing, industrial manufacturing etc. The small size of these particles and their ubiquitiousity in atmosphere has impacted human health adversely. It is predicted that high particle concentrations, particularly in the ultrafine range, can provoke alveolar inflammation, which in turn might release mediators capable of exacerbating lung disease and increasing blood coagulability in susceptible individuals [118]. Researchers in this field have reviewed that once deposited in lungs, these ultrafine and nanoparticles experience surface tension forces which results in their translocation by circulation to kidney, liver, heart and spleen where they might get deposited [119-121]. The chances of their translocation depend on their size, shape, solubility. Their residence time in respiratory tract along with the aforementioned factors determine their pathogenocity [122]. Paula et.al have emphasized on the probability that all inhaled particles, fibrous and nonfibrous, are likely to induce lung tumors in rats, if inhaled chronically or instilled intratracheally at sufficiently high dose and although the effect on human lungs is still not clear, evidences suggest that too much exposure for longer duration can produce the similar outcomes [123,124]. Neurodegenerative diseases (premature cell death) have been debated to be another adverse effect by nanoparticles. Brauner et. al. have concluded in their work that ultrafine particles (UFPs) may cause health effects through generation of oxidative stress which can consequently damage the DNA and other macromolecules [125]. The work on the toxicity of TiO_2 nanoparticles has evidences of hepatic injury, nephrotoxicity , myocardial damage and pathology change of kidneys in mice [126]. Association of aluminium with Alzheimer's disease is yet a controversial subject for research. As nanomaterials are a recently engineered, their toxicity is still under observation and research [127]. Risk assessment of nanomaterials is still in embryonic stage and stays a challenge to toxicological studies. There are variety of engineered nanostructured materials including those that are carbon-based (e.g., nanotubes, nanowires, fullerenes) and metal-based (e.g., gold, silver, quantum dots, metal oxides such as titanium dioxide and zinc oxide) and those that are more biological in nature (e.g., liposomes and viruses). The proliferation of market with consumer products involving engineered nanostructured materials has raised the debate over their toxicity [128]. Hammad et. al. have described a Gebel criterion for which might facilitate risk assessment of such materials [129]. Gebel has catogarized nanomaterials in three catogaries based on their toxicity- i) Category 1: Nanoparticles for which toxicity is mediated by the specific chemical properties of its components, ii) Category 2: biopersistent respirable fibrous nanomaterials and iii) Category 3 : respirable granular biodurable particles [130]. Catogary 2 and 3 pose the risk of serious respiratory diseases and their longer exposure may even risk lung cancer. Silver nanoparticles have been reported to posses higher cytotoxicity than asbestos in nano form. Nanoparticles can prove to be Pandora's box if not handled with prudence and care. The infamous Magic Nano spray incident of Germany has evoked a fresh debate about use of nanoparticles. Given the widespread use of nanotechnology at its very early stage, Antonio G. Spagnolo and Viviana Daloiso have suggested that the benefits of the medical and technological application of nanomaterials need to outweigh the risks and should be implemented under rigorous safety testing before going on any general release [131]. In an effort to understand the adverse impact of nanotechnology, Klaine et. al. have made a comprehensive study on its ill-effects from environmental issues to human health oulining effects from toxicity in packaging to pertubance to intertidal organisms and sandy shore ecosystems due to titanium nanoparticles [132]. The current requirement is to collaborate the nanotechnology with environmental science and human health system. It is imperative not to avoid long term effects on the altar of short term benefits and to devise greener way of using nanotechnology. The work by Moret et. al. can be cited as an example in this direction. They have tried to replace the potentially harmful CdTe quantum dots by ZnS quantum dots doped with copper (ZnS:Cu) for detection of bloody fingermarks on non porous surface[44]. Similar effort has been made by Yang et. al. to reduce the toxicity of carbon nanomaterials (carbon nanotubes, fullerenes, metallofullerenes, and graphenes) by modifying their surface chemical designs [133]. Many more examples of such kind would be welcomed in order to make nanosciences a durable saga rather than a short-lived scientific excursion.

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