Possible applications of nanotechnology in forensic & clinical toxicology sciences

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Aim: The practice of forensic pathology, forensic psychiatry, forensic odontology, forensic radiology, and forensic toxicology are all included in the multidisciplinary field of forensic medicine. The items involved in or produced by the crime are referred to as evidence, and the location where the crime was committed is known as the crime scene. The proof could be digital, chemical, or biological. Forensic technology is crucial in helping a team of forensic scientists analyze the evidence, judges, and prosecutors present evidence against offenders in a court of law. At crime scenes, several participants and samples have been collected for analysis. Revolutionary developments in crime scene investigation and evidence analysis have been made possible by the fusion of forensic science and nanotechnology. Nanotechnology provides innovative methods for identifying and lessening the impact of harmful compounds in the body in the setting of toxicology. Materials in the nanoscale, like nanoparticles and nanosensors, have special qualities that can be used to identify and treat poisoning. **Conclusion**: Even though nanotoxicology technology has advanced significantly, there are still several issues that need to be resolved. These include regulatory obstacles related to the clinical translation of nanomaterials as well as worries about their safety and biocompatibility. Furthermore, to guarantee broad adoption, the scalability and cost-effectiveness of nanotechnology-based techniques must be thoroughly assessed. The dearth of knowledge regarding the biological and environmental effects of nano-waste produced from nanomaterials is especially worrisome.

Keywords: forensic science, nanotechnology, clinical Toxicology, challenges

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BACKGROUND AND INTRODUCTION

Thanks to the capacity to manipulate atoms and molecules in materials at their most basic level through nanotechnology, innovative materials and technological progress with a variety of remarkable properties have been achieved. The term "Nano" is derived from the word "dwarf," signifying something small or one billionth of a meter, or 10^{-9}, which is approximately equal to one nanometer (nm). To illustrate, this scale is 40,000 times smaller than the thickness of a virus or a human hair (100 nm) or about 3–5 atoms wide [1]. Because of its diverse applications (Figure 1), the field of nano-forensics, a subset of forensic science, has incorporated it. Nano-forensics is a rapidly advancing area of innovation that utilizes nanotechnology [2]. The emergence of nanosensors has permitted the substitution of bulky instruments with smaller chip-based platforms, significantly aiding criminal investigations and enabling the identification of anonymous evidence through quicker and more accurate analysis methods [3].

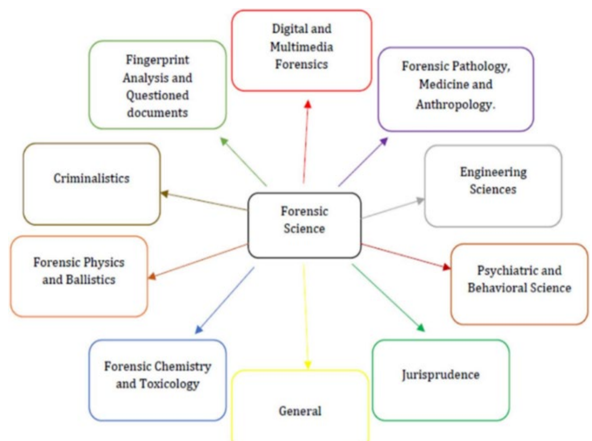

Figure 1. Different fields of Forensic as categorized by the American Academy of Forensic Sciences (2020).

TYPES OF NANOPARTICLES USED IN FORENSICS AND CLINICAL TOXICOLOGY [4,5]

Gold Nanoparticles

Gold nanoparticles (AuNPs) are one of the most important nanoparticles, and they have been widely used for medical and non-medical applications as ideal material because of their unique distinct features: inert, biocompatible, and especially due to low toxicity [6].

Silver Nanoparticles

Silver nanoparticles (AgNPs) are widely recognized for their unique optical, electronic, and antibacterial properties, enabling their use in biosensing, photonics, electronics, drug delivery, and antimicrobial treatments [7].

Quantum dots

Quantum dots (QDs) or semiconductor nanocrystals are semiconductor particles a few nanometres in size with optical and electronic properties that differ from those of larger particles via quantum mechanical effects. They are a central topic in nanotechnology and materials science. When a quantum dot is illuminated by UV light, an electron in the quantum dot can be excited to a state of higher energy [8].

Magnetic nanoparticles

Magnetic nanoparticles (MNPs) are a class of nanoparticles that can be manipulated using magnetic fields. Such particles commonly consist of two components, a magnetic material, often iron, nickel and cobalt, and a chemical component that has functionality. While nanoparticles are smaller than 1 micrometer in diameter (typically 1–100 nanometers), the larger microbeads are 0.5–500 micrometer in diameter [9].

Silica nanoparticles

Silica nanoparticles are the mostly used nanomaterials to build pH nanosensor. Silica nanoparticles are optically transparent, of low toxicity, inert to pH, and (some are) degradable [10].

POSSIBLE APPLICATIONS IN FORENSIC SCIENCES

Detection of Latent Fingerprints

Fingerprints are among the most prevalent types of evidence encountered at nearly all crime scenes and hold significant importance. Currently, a variety of nanopowders are employed to reveal latent fingerprints on diverse surfaces. Recently, researchers have developed a novel ZnO-SiO2 nanopowder that is effectively utilized with the small particle reagent (SPR) method to enhance latent fingerprints. Furthermore, the quality of fingerprints found on the adhesive side of black tape and those contaminated with blood can be improved using titanium dioxide (TiO2-NPs) powder [11,12].

DNA analysis

DNA serves as a crucial piece of supporting evidence, providing clear indication of an individual's presence or absence at a crime scene. Studies have demonstrated that magnetic nanoparticles can effectively extract DNA from a range of biological samples, such as hair, blood, saliva, skin, and semen [13].

Detection of explosives and chemical warfare agents

The use of polymer particles and nanoparticles combined with various nanosensor devices, including nano-curcumin-based probes, electronic nose systems, nanowires or nanotubes, and plasmon nanocavities for laser-induced resonance, results in alterations in their measurable properties when they interact with explosives, facilitating precise and targeted detection [14].

Forensic toxicology

Forensic toxicology effectively employs modern nanotechnology to identify and measure toxic substances found in various forensic samples, including blood, hair, saliva, urine, vitreous humor, fingerprints, and skeletal remnants. Advanced nano-techniques such as HPLC (high-performance liquid chromatography), XPS (X-ray photoelectron spectroscopy), and Tof-MS (Time-of-flight mass spectrometry) are utilized for the detection of a diverse array of compounds, spanning from legal drugs like paracetamol to illicit narcotics such as morphine, cocaine, heroin, and barbiturates [15].

Questioned documents

Researchers have focused on utilizing gold nanoparticles without solvents to enhance the LDI-MS (Laser Desorption/Ionization Mass Spectrometry) technique. This approach allows for the detection of ink images and visible dyes present on banknotes and contested documents, facilitating the analysis of unique ink stroke patterns for the identification of forgery or alterations [16].

Hair and fibres

With a thorough and organized search, even the smallest pieces of evidence, such as hair and fibres, can be discovered at a crime scene. Because of their size, these little data points are easy to overlook, challenging in-depth studies. Traditionally, X-ray microdiffraction, optical microscopy, transmission electron microscopy (TEM), and surveying electron microscopy (SEM) have been used to achieve this. Forensic investigations are being supported by the non-destructive Nanoscope III multimode AFM (atomic force microscopy) analysis of hair and fibre structure [17].

Time since death (TSD) estimation

One of the most important problems in forensic medicine and legal practice is determining the time since death (TSD), sometimes known as the time of death. One fluid that persists even after a long time after death is vitreous humour (VH). This implies that VH's metabolic alterations that affect variations in amino acid levels occur gradually. Consequently, by closely analyzing these metabolic alterations, a precise time since death (TSD) computation can be performed. Modern science has created a novel, efficient, and reasonably priced lab-on-chip technique that makes it possible to quickly assess the amino acid cysteine. Up to 96 hours may pass during this examination, during which time VH cysteine contents notably rise and the course of TSD becomes linearly associated. Fluorescent nanoparticles will eventually be able to measure and quantify VH concentration using flow cytometry. This state-of-the-art method would increase the accuracy of TSD estimation [18].

Analysis of bloodstains

Harm was done when blood is discovered at a crime scene, and it can be used to identify the victim or the perpetrator when it is examined and transferred to DNA analysis. The bloodstain pattern also aids in reconstruction and helps forensic specialists and crime scene investigators comprehend what occurred at the spot. Force spectroscopy (FS) has been used in research to determine the age of bloodstains at crime scenes and to estimate the time of the incident from the time of deposition. Similarly, atomic force microscopy (AFM) has been used to estimate the time since death (TSD) of red blood cells found in bloodstains. Recent research indicates that this important field of forensic science can be addressed by atomic force microscopy (AFM). Being a new tool, AFM can help legal and medical experts in crime investigation by making it easier to determine the age of bloodstains and the time of death [19].

FUTURE PERSPECTIVES

The most intriguing advancement that could help reduce laboratory contamination concerns is the possible integration of all laboratory operations onto a nanoplatform. Advanced nanotechnology techniques such as nanochips, nanoprobes, and nanodevices can be useful strategies for reducing crime and enhancing societal security. Violent crimes, rape, murder, theft, fraud, and terrorist assaults are just a few of the illegal acts that nanotechnology can assist shield people from. It can also be used to protect old people, teens, and children against abduction, cybercrime, and kidnapping.

CONCLUSION

Given the advancements in nanotechnology over the past couple decades, nano-forensics may be crucial to the resolution of criminal cases. To detect explosives, detect illegal narcotics, analyze gunshot residue, analyze DNA, visualize fingerprints, and more, many kinds of nanoparticles, nanoprobes, nanosensors, and quantum dots have been tested. They are used less frequently, though. The use of nanomaterials in scientific evidence analysis is something that forensic scientists ought to be aware of. To improve the current technology, more study in this area is needed. There is great promise to use nanotechnology to solve horrible crimes in society.

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