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REVIEW | OPEN ACCESS

Utility of Nanotechnology for the Practitioners of Medicine, Forensic Medicine & Toxicology

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ABSTRACT: Nanotechnology has emerged as a transformative tool in different disciplines of medicine including forensic medicine and toxicology, enabling practitioners to analyse evidence with unparalleled precision and efficiency. This review explores the multifaceted applications of nanotechnology in the practice of medicine, forensic investigations, toxicological assessments, and crime scene analysis. It focuses on nanoscale materials and techniques that enhance sensitivity, facilitate rapid detection, and improve imaging. The review also delves into challenges such as ethical considerations and technical limitations while highlighting prospects for integrating nanotechnology into medical practice and forensic practices. Through scientific innovation, nanotechnology promises to revolutionize medicine, forensic medicine and toxicology, ensuring more accurate diagnosis and rapid justice.

Keywords: Nanotechnology, Nanomaterial Characterization, Forensic Medicine, Toxicology, Nano-Forensics, Evidence Analysis, Crime Scene Investigation.

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INTRODUCTION

Nanotechnology, artificial intelligence and DNA profiling are the future of sciences and all the students of medicine and forensic sciences must know these emerging fields and how to use these in their respective areas of specialization. Practitioners of various disciplines of medicine should understand how nanoscience can be of help in their fields of specialization. To use Nanotechnology all the students and researchers in this field must have the technical knowledge of the use and utility of Transmission Electron Microscope (TEM), Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and Brunauer-Emmett-Teller analysis (BET) for the characterization of the nanomaterials. BET analysis especially helps in knowing the specific surface area of the nano-materials.[1]

Nanotechnology, defined as the manipulation of matter at dimensions typically below 100 nanometres, has revolutionized scientific domains, including forensic medicine and toxicology. The unique properties of nanomaterials, such as enhanced surface area, reactivity, and optical capabilities, have rendered them invaluable for evidence detection and analysis.[2] This review examines the utility of nanotechnology in forensic applications, focusing on its pivotal role in identifying crime scene evidence, toxicological analysis, and advancing forensic imaging methods.

We have moved from the Stone Age to the Nano Age after going through the Bronze Age, Iron Age, Plastic Age, and Silicon Age. Nanomaterial is the material ranging from 0.1 nanometres to 100 manometers. Nanotechnology is being utilized in various fields helping in improving the daily life of the people. It is being used in different fields e.g.

forensic sciences, medicine, sports, textiles, cosmetics, electronics and biosensors.[3-9] It the medical field it is being used in various branches of medicine and surgery. It can be useful in diagnostics, imaging and drug delivery especially to treat cancer patients. It can be used in therapeutics and regenerative medicine.[10]

In drug delivery nanoparticles are used to deliver the medicines to the target organs thus reducing the side effects by decreasing the dose to be given to the person and making treatment better as the medicine is delivered to the target organ and also helps in regenerating tissues and helping in tissue engineering.[11] In diagnostics, there is early detection of the disease by better detection of biomarkers for the disease. It is especially useful for diagnosing infectious diseases.[12] In imaging visualizations of organs and tissue become better by using nanotechnology. It helps in visualizing microstructures and micro lesions.[13] It is also used in surgical branches ranging from vascular surgery, heart surgery, neurosurgery, and plastic surgery to orthopaedic surgery, and minimal surgery.[14]

It can be used in drug detection in the body.[3] It is also being used in the forensic sciences in the sensor technology for trace evidence detection and identification of explosives and toxins.[3, 15] It is also used detection of body fluids with the help of lateral flow assays and helps in extracting DNA from various body fluids e.g. semen, blood and saliva.[16] It can be used in quantification of the DNA.[3] In is also used in DNA Analysis as Nanoparticles can improve the extraction and amplification of DNA material. Nono gold particles also improve the PCR of DNA material. The efficiency of PCR increases with the addition of nanogold particles into PCR reagents size of which is usually 0.7nm to 13 nm.[17] Nanomaterials of gold can increase sensitivity and specificity along with the efficiency of the PCR process.[18]

The use of nanomaterials will result in poisoning by nanomaterials as these particles have great tissue penetration due to their smaller size and morphology; their surface chemistry and surface charge further help in this penetration. A new field of Nanotoxicology will be required to deal with it[11]. It is also used in questioned document analysis by using atomic force microscopy.[3] It can also be used for analysis of materials finding out their surface characteristics by high resolution images with the help of SEM and TEM. Characterization of the nanomaterials can be done by using FTIR Spectroscopy, SEM, TEM & BET.[19, 20] Nanoparticles can also improve the detection of latent fingerprints.[3] Different nanomaterials can be used which may range from metal nanoparticles, dots (quantum, carbon and polymer) fluorescent silica & mesoporous silica nanoparticles.[21]

Nanotechnology can also be helpful in toxicology in detecting toxins, especially by colourimetric methods to detect toxins quickly in contaminated food[22]. Nanotechnology may help in virtual autopsy.[3] Through a robotic system using nanotechnology 3D surface scanning is done and automatic image-guided biopsies during Virtual postmortem examination.[23]

METHODS

The review compiles findings from peer-reviewed journals, case studies, and experimental research on nanotechnology's forensic applications. Methodologies include:

1. **Utilization of Nanomaterials:** Investigating nanoparticles like silver, gold, and quantum dots for detecting latent fingerprints and biological traces.[24]
2. **Analytical Techniques:** Highlighting the role of electron microscopy, Raman spectroscopy, and nano-sensors in forensic examinations.[25]
3. **Case Studies:** Presenting real-world applications of nanotechnology in solving complex forensic cases, such as poison detection and drug analysis.

RESULTS

1. Enhanced Evidence Detection Nanoparticles amplify the detection of biological and chemical evidence, making previously undetectable residues visible under high-resolution imaging systems.[2] For example, gold nanoparticles tagged with antibodies facilitate the identification of trace quantities of blood or saliva samples. Additionally, carbon nanotubes enhance the accuracy of latent fingerprint visualization.
2. Rapid Toxicological Analysis Nano-based assays have revolutionized the detection of drugs, poisons, and hazardous chemicals in biological fluids. Quantum dots, coupled with advanced fluorescence techniques, provide rapid and precise toxicological analysis.[24] This has

significantly accelerated forensic investigations, especially in cases of suspected poisoning.

3. Improved Crime Scene Imaging High-resolution imaging using nanoscale technologies enables detailed reconstructions of crime scenes, preserving evidence integrity. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) assist in analysing micro-fragments, such as gunshot residue and paint chips.[25]
4. Drug Identification Nanotechnology aids in identifying illicit drugs and their metabolites through nanosensors and surface-enhanced Raman spectroscopy (SERS), even in challenging sample conditions.[2]

DISCUSSION

In the medical field, the big impact is going to be on drug delivery, imaging, diagnostics, regenerative medicine and therapeutics.[1] The areas which will see the greatest impact are evidence detection and identification, forensic material characterization, DNA analysis, latent fingerprints technology and toxicology in forensic sciences. Nanotechnology has transformed forensic practices by enhancing sensitivity, accelerating analysis, and improving accuracy. However, challenges remain:

Technical Limitations: The deployment of nanotechnology in forensic labs demands high expertise and resources, which may not be feasible for all institutions.[24]

Ethical Concerns: The potential misuse of nanoscale surveillance tools raises privacy issues and ethical dilemmas.

Standardization: The lack of uniform protocols for nanotechnology application in forensic investigations complicates global adoption.

Prospects include the development of cost-effective nanomaterials and automated nanosensors for real-time forensic analysis. Collaborative research between forensic scientists and nanotechnology experts will play a crucial role in overcoming current limitations.

CONCLUSION

Nanotechnology has become an indispensable asset for all fields of medicine. This will be especially useful for the practitioners of forensic medicine and toxicology, offering precision, speed, and accuracy in evidence detection and analysis. Its applications have advanced toxicology, crime scene investigation, and drug detection techniques. Addressing challenges such as ethical concerns and standardization will further enhance its utility. Continued innovations in nanotechnology promise to reshape the practice of medicine and the forensic landscape, ensuring justice through scientific ingenuity.

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