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NANOBIOTECHNOLOGY: AN OVERVIEW

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ABSTRACT

The increasing integration of engineered nanoparticles into human and environmental contexts parallels the rapid advancement of nanotechnology. Nanoparticles interact with membranes, cells, DNA, and organelles through colloidal forces and dynamic biophysiochemical interactions, forming diverse nanoparticle/biological interfaces. Revolutionary nanosystems have demonstrated significant potential in monitoring and safeguarding biological systems. The concept of nano-bio interfaces has become feasible through the rapid progress in integrating biological entities with programmable nanomaterials. However, challenges such as potential toxicity, immunogenicity, and reduced efficacy hinder the widespread biomedical application of nanomaterials. Understanding the intricate relationships within nano-bio interactions remains incomplete, limiting the clinical effectiveness of nanomedicines. Despite these challenges, nanomaterials exhibit immense promise as powerful diagnostic and therapeutic tools in various nanomedicine applications. Harnessing the exceptional magnetic, optical, and photothermal properties of inorganic nanoparticles for multifunctional molecular imaging necessitates engineering them with a biocompatible shell to optimize their physicochemical characteristics.

KEYWORDS: nanoparticles, nanobiotechnology, and nano-bio interactions.

INTRODUCTION

Recently, DNA has taken on multiple roles, serving as a foundational material for nanoscale engineering and as the principal genetic molecule within biological systems.

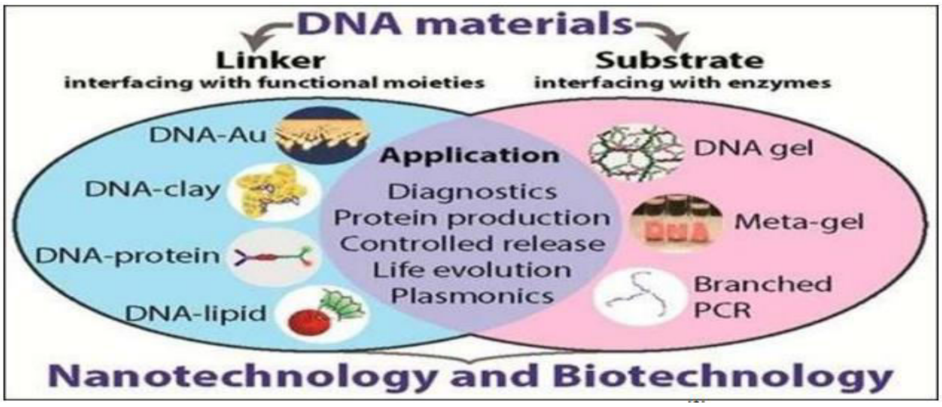

Fig.1 Nano-technology and Bio-technology

The translation of biomedical nanomaterials from bench to bedside remains challenging despite rapid advancements. Biomolecules can induce phase changes, release free energy, trigger reorganization, and cause dissolution at the surface of nanomaterials. For instance, only a median of 0.7 of the injected dose of targeted nanoparticles (TNPs) for medication delivery accumulates in solid tumors[1].

The term "bio-nano things" denotes fundamental structural and functional components uniquely identifiable and operational within the biological environment. Enabled by nanotechnology and synthetic biology, Bio-Nano Things in the Internet of Things (IoT) are anticipated to perform sensing, processing, actuation, and interactive functions typical of embedded computing systems[2].

- **Biological cells as Bio-Nano Thing substrates:** Biological cells, the fundamental units of life, consist of membranes enclosing specialized molecules with specific chemical compositions and functions. Drawing an analogy between electron propagation in semiconductors and biological reactions highlights functional similarities, albeit with greater complexity in biological systems[3].
- **Targeted nanoparticles, biochemical processes, and medication delivery:** Targeted drug delivery using TNPs has garnered attention for its potential to minimize toxicity, evade immune clearance, achieve tissue penetration, and target cellular uptake. However, optimizing physicochemical parameters to simultaneously achieve molecular targeting, nanoparticle trafficking, and controlled drug release remains a significant challenge hindering clinical translation. Various approaches, such as creating diverse nanoparticle libraries and optimizing surface functionalization, aim to enhance specific binding affinities to cell-surface receptors. Examples include the development of targeted polymeric nanoparticles containing chemotherapeutic agents for prostate tumors and efficient gene-delivery formulations for fibroblast and cancer cell lines[4].
- **Combinatorial approaches in nanotechnology:** Researchers have utilized combinatorial methods to develop diverse nanoparticle libraries tailored for specific biomedical applications. These include high-throughput electrochemical sensors for detecting genetic mutations in circulating tumor nucleic acids and optimizing nanomaterials for efficient siRNA delivery. Additionally, advancements in tissue engineering are reshaping biophysiochemical interactions at interfaces through the programmable manipulation of nanomaterials' physicochemical properties [5].

The bio-nano interface imparts nanoparticles with a biological identity: Recently, [6], the critical role of nanoparticles' interactions with biological molecules has become evident in both nanomedicine and nanotoxicity studies. Nanoparticles exhibit characteristics of mobile solids, combining properties like solid-state attributes (e.g., fluorescence in quantum dots where components are originally non-fluorescent) with the ability to thermally diffuse, akin to molecules, as highlighted in a recent review of their interactions with biological systems.[7] These interactions significantly influence the biological behavior and impacts of nanoparticles. The hypothesis from 1990 posited that inhaled airborne particles would become coated with lung surfactant lipid, underscoring the importance of the bio-nano interface and its potential pivotal role in ensuring the safe deployment of nanotechnologies and nanomedicine. Despite its importance, efforts to characterize this interface have been surprisingly limited.[8] The OECD's inclusion of nanoparticle characterization in biofluids as an endpoint underscores the widespread recognition of the nanoparticle biomolecule corona concept and the significance of the bio-nano interface.[9] The burgeoning field of nanotoxicology focuses on investigating adverse interactions between artificial nanoparticles and cellular nanostructures or nanomachines.

Table 1: Adsorbed biomolecules as well as the surface and dispersion of nanoparticles are affected by interactions between nanoparticles and biomolecules and the creation of the bio-nano interface.

Sr.no	Effect of absorption on Biomolecules	Effect of interaction of nano-particles
1	Depletion of medium components which can results in indirect toxicity effect [21,22,23]	Masking targeting or other bio-functional elements? (possibly only temporarily) [24]
2	Oxidative effects-lesions post-transitional effects[25]	Reduce surface energy or reactivity[26]
3	Altered propensity for protein-protein interactions (e.g. Fibrillation) [27]	Altered surface characteristics and thereby stability and dispersibility [28]and potentially also dissolution potential (as per environmental macromolecules such as hemic acid) although limited literature [29]
4	Altered kinetics (distribution, half-life, degradation, etc.) [30,31]	Altered bioactivity[32,33]
5	Confirmation changes: blocked or enhanced presentation of active sites and subsequent functional changes. [34]	Conferring a biological identity: altered interaction or uptake and biodistribution. [35]

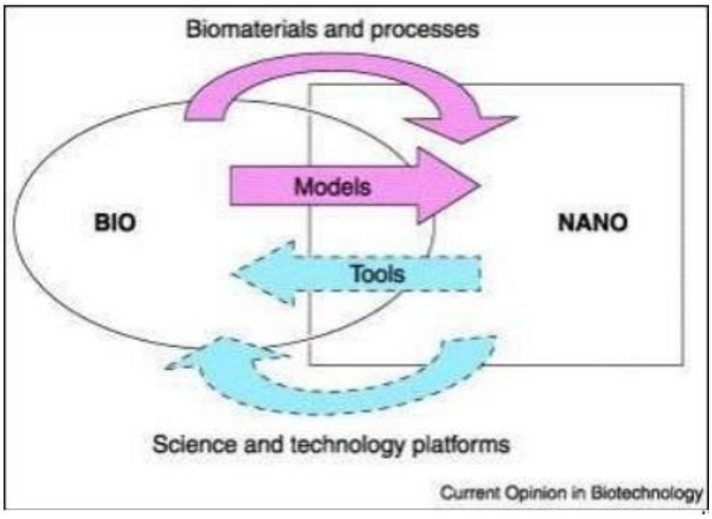

Fig2: key interaction between field of biology and nanotechnology

The application of nanobiotechnology spans across various fields including agriculture, biofuel production, cancer immunotherapy, carbon capture, and biomarker detection using nano biochips, nanoelectrodes, or nano biosensors[10].

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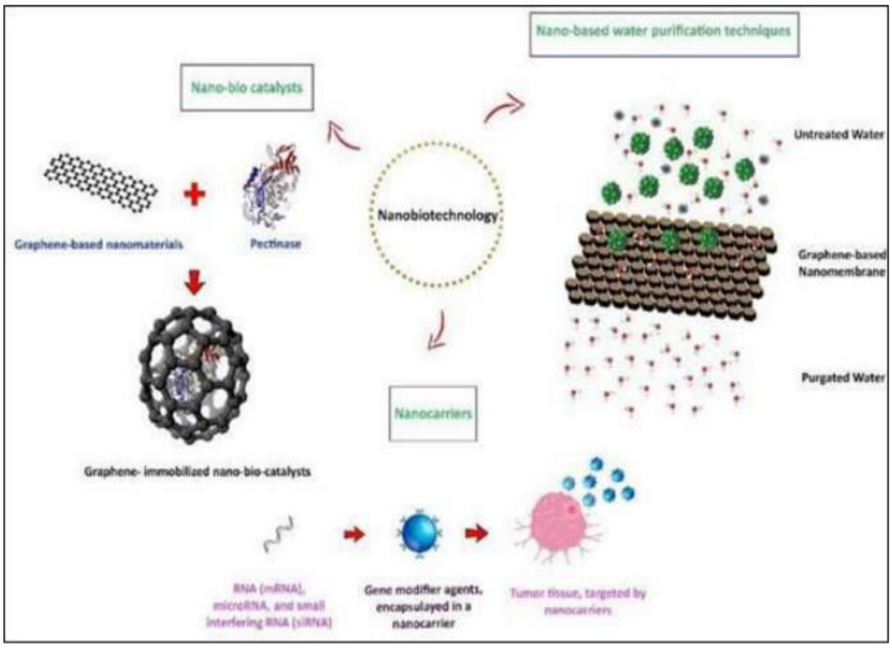

Fig 3: Diverse Applications of Nanobiotechnology: multiple techniques, including Drug delivery-based therapies, remediating processes,and industrial nano-biocatalysts benefit from nano-scaled particles

CONCLUSION

By integrating nanotechnology with biotechnology, scientists can develop faster, more cost-effective, and efficient procedures. This nano-biotechnological approach significantly impacts various industrial, agricultural, environmental, and therapeutic applications. This review has examined current advancements and challenges in biotechnology, highlighting how nanotechnology offers alternative solutions. Specifically, we have discussed the latest developments in corona and redox-driven nano-bio interactions of nanomaterials, paving the way for their future application in biomedicine.

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