Nano–Bio Interface Engineering for Targeted Drug Delivery in Neurodegenerative Disorders

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***Abstract*—Neurodegenerative disorders such as Alzheimer's, Parkinson's, and Huntington's disease present significant therapeutic challenges due to the complexity of neuronal networks, the presence of the blood–brain barrier (BBB), and the need for spatiotemporally precise drug delivery. Nano–bio interface engineering has emerged as a transformative strategy for designing targeted delivery platforms capable of navigating the unique biochemical and biophysical environment of the central nervous system (CNS). This paper reviews innovative nanomaterial platforms—including polymeric nanoparticles, lipid-based nanocarriers, inorganic nanosystems, and bioengineered hybrid constructs—designed to modulate cell–nanoparticle interactions, enhance BBB translocation, and achieve controlled release at neuronal targets. Emphasis is placed on surface functionalization, ligand-receptor binding specificity, stimulus-responsive architectures, and nano–bio mechanical interactions that determine biocompatibility, circulation time, and targeting precision. The analysis highlights how molecular-scale interface engineering enables therapeutic agents to reach pathological sites with improved efficacy while minimizing off-target effects. Collectively, emerging nano-enabled strategies offer promising avenues for next-generation treatments aimed at slowing or reversing the progression of neurodegenerative diseases.**

Neurodegenerative disorders remain among the most difficult medical conditions to treat, largely due to the brain's highly selective physiological barriers and the intricacy of cellular signaling pathways underlying neural function. Conventional pharmacological treatments suffer from poor bioavailability in neural tissues, rapid systemic clearance, and limited ability to reach diseased regions with therapeutic concentration [5]. The blood–brain barrier (BBB), while essential for maintaining neural homeostasis, restricts approximately 98% of small-molecule drugs and nearly all large biologics, rendering many promising therapies ineffective once administered systemically. As the global prevalence of neurodegenerative diseases continues to rise, the need for innovative delivery systems capable of targeted, efficient, and safe CNS drug transport has become more urgent [6].

Nano–bio interface engineering represents one of the most promising directions in this endeavor. By designing nanocarriers whose physicochemical

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