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Mini Review:

Overview of DNA Nanotechnology: Types, Principles, Design, and Applications

"Innovations of DNA Nanotechnology"

Hanan R.H Mohamed

Zoology Department, Faculty of Science, Cairo University, Giza, Egypt; Correspondence to: hananeeyra@cu.edu.eg **DOI: 10.21608/RRGG.2024.36951. Received: 5 July 2024; accepted: 25 July 2024; published 27 July 2024**

Abstract

DNA nanotechnology has emerged as a promising field with vast potential in various applications, ranging from drug delivery to molecular computing. This review article aims to provide an overview of recent advancements in DNA nanotechnology, focusing on its principles, methodologies, and applications. Through an analysis of key studies and experiments, this review highlights the versatility and promising future of DNA nanotechnology in diverse fields.

Keywords: DNA Nanotechnology; definitions; applications; DNA nanodevices and nanostructures

1. DNA nanotechnology

DNA nanotechnology is a burgeoning field with vast potential for applications in various domains **(Mathur and Igor, 2017)**. DNA nanotechnology is the design and manufacture of artificial nucleic acid structures for technological uses as nucleic acids are used as non-biological engineering materials for nanotechnology rather than as the carriers of genetic information in living cells **(Goodman *et al.*, 2005)**. DNA nanotechnology, utilizing the programmability and self-assembly properties of DNA molecules, has garnered significant attention in recent years **(Seeman, 2003)**.

Researchers have created static structures such as two- and three-dimensional crystal lattices, nanotubes, polyhedral, and arbitrary shapes as well as functional devices such as molecular machines and DNA computers with precise control over size, shape, and functionality as shown in Fig. 1 **(Li *et al.*, 2018; Mao *et al.*, 2022)**.

Thus these structures are beginning to be used as a tool to solve basic science problems in structural biology and biophysics, including applications in X-ray crystallography and nuclear magnetic resonance spectroscopy of proteins to determine structures. These DNA-based structures also hold promise in diverse areas such as drug delivery **(Chi *et al.*, 2020)**, biosensing **(Wang *et al.*, 2020)**, and nano-electronics **(Li *et al.*, 2018).** Moreover, DNA nanotechnology offers a platform for bottom-up fabrication at the nanoscale, facilitating the development of novel materials and devices **(Li *et al.*, 2018; Mao *et al.*, 2022)**.

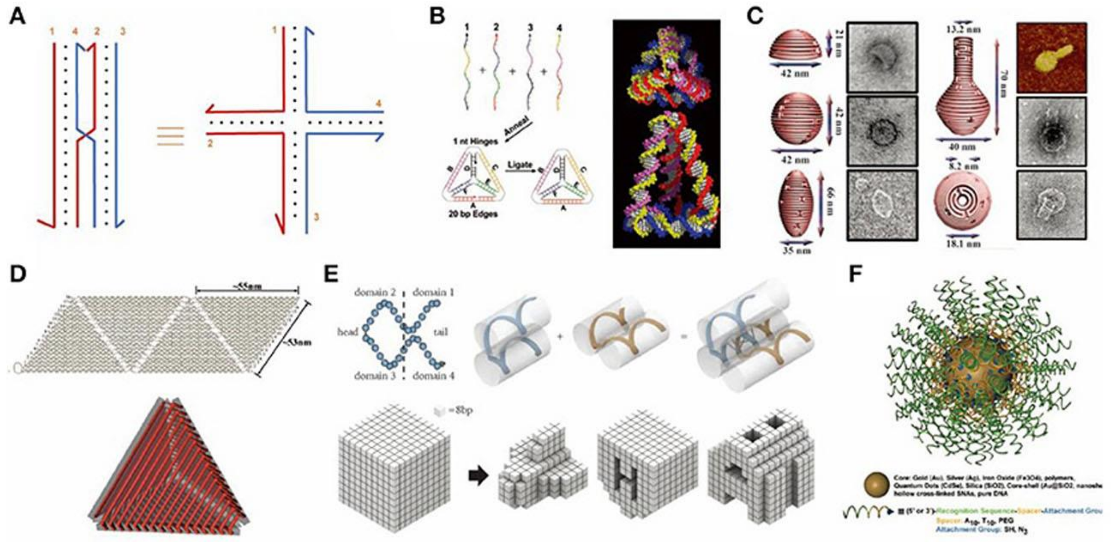

Fig. 1: DNA nanostructures. A) Holliday junction. B) DNA tetrahedron formed from 4 single-stranded DNAs (Goodman *et al.*, 2005). C) 3D DNA origami structure with precisely controlled curvature (Han *et al.*, 2011). D) DNA container constructed by folding and joining single-layered 2D origami sheets (Ke *et al.*, 2009). E) DNA objects assembled from single-stranded tiles or DNA bricks (Ke *et al.*, 2012). F) Spherical nucleic acids tethered onto a gold nanoparticle core (Cutler *et al.*, 2012).

2. Principles of DNA Nanotechnology

The fundamental principle of DNA nanotechnology lies in the ability to design and manipulate DNA molecules to create nanostructures with precise control and specificity **(Rothemund, 2006)**. By exploiting the complementary base pairing of DNA strands, researchers can engineer intricate nanostructures, such as DNA origami and DNA tiles, with remarkable precision **(Douglas *et al.*, 2009)**.

3. Methodologies in DNA Nanotechnology

Various methodologies have been developed to fabricate DNA nanostructures, including scaffolded DNA origami **(Rothemund, 2006)**, DNA tile-based self-assembly **(Yin *et al.*, 2008)**, and DNA brick construction **(Ke *et al.*, 2012)**.

These methodologies offer versatile approaches to design and fabricate complex DNA nanostructures with diverse shapes, sizes, and functionalities.

4. Types

DNA nanotechnology involves the manipulation of DNA molecules to construct nanoscale structures with precise control over size, shape, and functionality **(Roh *et al.*, 2016)**. This burgeoning field encompasses various types of DNA-based nanostructures, including DNA origami, DNA tile assembly, DNA nanorobotics, and DNA nanocages **(Yin *et al.*, 2008; Li *et al.*, 2018; Chi *et al.*, 2020; Wang *et al.*, 2020; Mao *et al.*, 2022)**.

DNA Origami: In DNA origami, a long single-stranded DNA scaffold is folded into desired shapes by short staple strands through Watson-Crick base pairing.

DNA Tile Assembly: DNA tile assembly involves the use of short DNA strands to form larger structures through complementary base pairing interactions.

DNA Nanorobotics: DNA nanorobotics integrates dynamic DNA components to perform mechanical tasks at the nanoscale, such as cargo delivery or molecular sensing.

DNA Nanocages: DNA nanocages are hollow structures constructed from DNA strands, capable of encapsulating molecules for targeted delivery or controlled release.

5. Design

Designing DNA nanostructures involves careful consideration of sequence design, topology design, and functionalization as seen in Fig. 2 **(Douglas and Dietz, 2018).**

Sequence Design: Designing the DNA sequences involves careful consideration of complementary base pairing and structural constraints to achieve desired shapes and functionalities.

Topology Design: Topology design focuses on arranging DNA strands to create complex structures with specific geometries and properties.

Functionalization: Functionalization involves attaching various molecules, such as proteins or nanoparticles, to DNA nanostructures to confer specific functionalities or targeting capabilities.

6. Applications of DNA Nanotechnology

DNA nanotechnology holds immense potential in numerous applications, including nanomedicine, biosensing, and nanoelectronics. In nanomedicine, DNA nanostructures can serve as drug delivery vehicles **(Perrault and Shih, 2014; Wang *et al.*, 2020)** and promising therapeutic agents for targeted cancer treatment **(Zhang *et al.*, 2014)**.

Additionally, DNA nanodevices have been employed for sensitive detection of biomolecules in biosensing applications **(Li *et al.*, 2018)**. Furthermore, DNA-based nanoelectronic devices offer novel opportunities for constructing molecular circuits and computing systems **(Seelig *et al.*, 2006)**.

Drug Delivery: DNA nanotechnology enables the design of drug delivery vehicles with precise control over cargo loading, release kinetics, and targeting capabilities.

Biosensing: DNA nanostructures can be utilized as biosensors for detecting biomolecules, pathogens, or environmental pollutants with high sensitivity and specificity.

Nanoelectronics: DNA-based nanoelectronic devices, such as nanowires and molecular switches, hold promise for applications in nanoelectronics, including molecular computing and sensing.

Therapeutics: DNA nanotechnology offers potential in therapeutic applications, such as gene editing, gene delivery, and targeted cancer therapy, through precise control over molecular interactions and cellular processes.

Materials Science: DNA nanostructures serve as building blocks for creating novel materials with tailored properties, including photonic crystals, scaffolds for tissue engineering, and nanoscale templates for material synthesis.

DNA nanotechnology thus continues to evolve, offering innovative solutions across diverse fields and paving the way for advancements in nanoscience, biotechnology, and medicine.

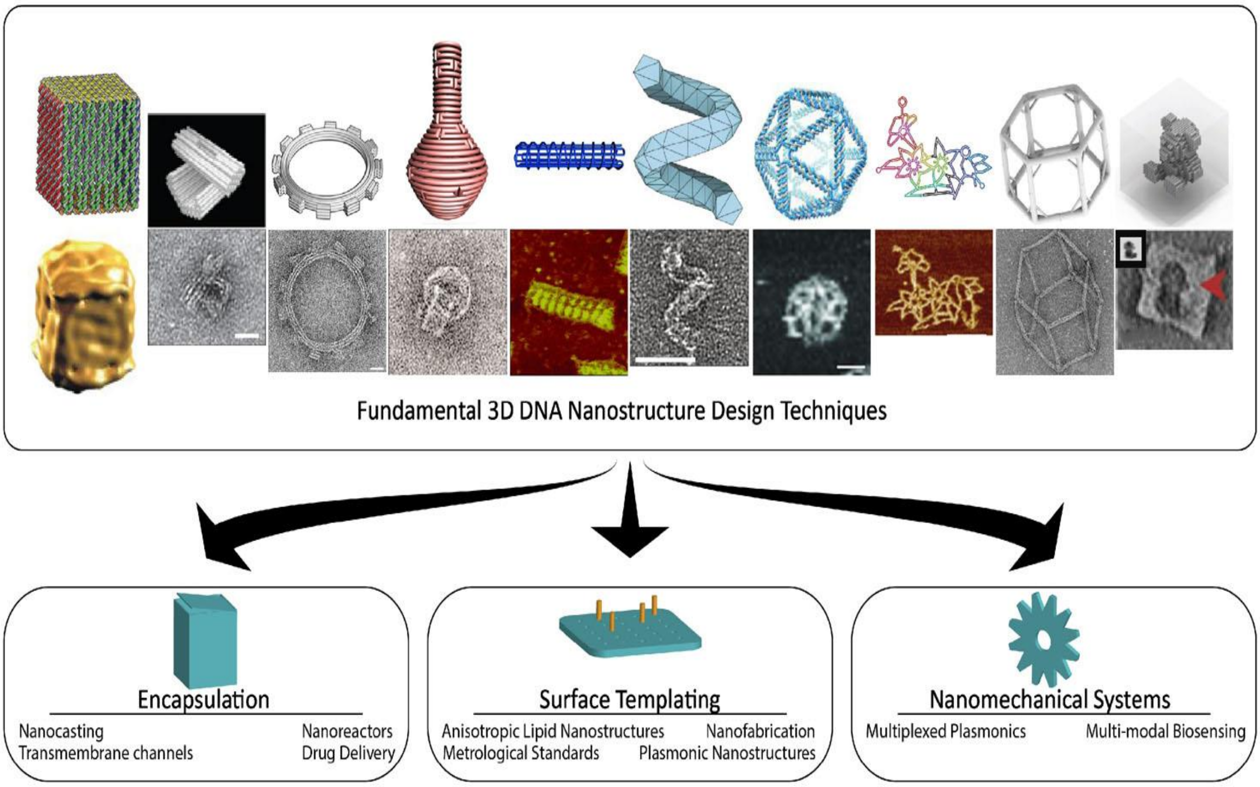

Fig. 2: Design of DNA nanostructures (Fu D and Reif, 2021)

7. Conclusion

In conclusion, DNA nanotechnology represents a versatile platform for engineering nanoscale structures with diverse applications across various domains. By harnessing the unique properties of DNA molecules, researchers continue to explore innovative applications and functionalities of DNA nanostructures. As technologies evolve and methodologies improve, the future of DNA nanotechnology holds exciting prospects for addressing complex challenges in healthcare, electronics, and beyond.

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