Current Trends in Biomedical Engineering & Biosciences
ISSN: 2572-1151

Juniper Publishers
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Mini Review
Volume 21 Issue 1 - July 2022
DOI: 10.19080/CTBEB.2022.21.556052

Curr Trends Biomedical Eng & Biosci

Carbohydrate-Based Nanoparticles in Therapeutics and Biomedicine

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Submission: July 12, 2022; **Published:** July 26, 2022

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Abstract

Nanotechnology is a new emerging technology that is actively used in modern biomedicine and research. Of the various types of NPs, carbohydrate/saccharide-based NPs find their application in the therapy and diagnosis of various disorders and diseases due to their natural origin and the importance of carbohydrate components in biological processes. Biological permeability and natural glycans provide various advantages for their use in the field of medicine.

Keywords: Carbohydrate; Drug delivery; Glycan; Nanoparticles; Saccharide; Therapeutics

Introduction

Nanoscience, which deals with Nanoparticles (NPs) of size < 100nm that possess unique properties, has become a new technology in recent decades. Moreover, the fusion of nanotechnology with other disciplines has led to a revolution as in the field of biomedicine, which has become a major focus in bioresearch. Since the cell and all its components such as macromolecules and proteins are micrometers and nanometers in size, NPs can be used as carrier molecules and for biological detection without excessive interference. This size comparison and the advantage of using NPs is the driving force behind the rapid development of nanotechnology in the field of life sciences and biomedicine [1]. Moreover, the ability to modify their physical properties by changing their size makes them an interesting candidate in pharmaceuticals and biomedicine. The small size, large surface area, biological mobility and chemical stability of NPs make them a suitable candidate for biomedical applications such as carrier molecules for drug and gene therapy, tissue engineering, biosensors, etc. [2].

The NPs can be of different types based on their chemical composition, e.g. carbon compounds such as fullerenes and nanotubes or inorganic compounds such as metals, oxides, ceramics, quantum dots, or organic liposomes and polymers. Since the chemical properties of the base material that makes up the NPs are preserved, they play an important role in deciding which NP to select for various medical applications [3]. Most clinically approved NPs are liposomal or polymeric in nature, such as Myocet, Copaxone, Naulasta, Abelcet, etc. [2]. Considering the negative impact of bulk materials that make up NP, the use of environmentally friendly natural polymers, i.e., carbohydrates and proteins, has come to the forefront in recent years. This mini review focuses on recent advances in the use of carbohydrate-based NPs in the biomedical field.

Carbohydrate based Nanoparticles in Biomedicine

Carbohydrates are the most abundant molecules with ubiquitous nature and multiple functions in living forms. They are the most important cellular molecules and help in cell-to-cell recognition by interacting with other molecules such as proteins, glycol conjugates, etc. Considering their importance in biological processes, the study of glycan components is necessary [4]. However, the problem of large chain length and the inability to monitor the low intensity of carbohydrate effects in biological processes have led to the development of carbohydrate technologies and NPs from carbohydrates (Figure 1) [5]. The addition of multiple valences can help increase the detection limit of these saccharides, which is achieved in saccharide-based NPs. In addition, carbohydrate-based NPs have a similar size to most biological molecules and can mimic sugar molecules and therefore can be used as probes to study glycan-glycan or glycan-protein interactions. Thus, these NPs find their use in diagnosis and as biomarkers. Moreover, carbohydrate-based NPs have discovered their potential as carriers of bioactive molecules due to their biocompatibility and biodegradability, apart from their size [6]. Table 1 provides the latest information on the biomedical applications of the various sugar-based NPs in the biomedical field.

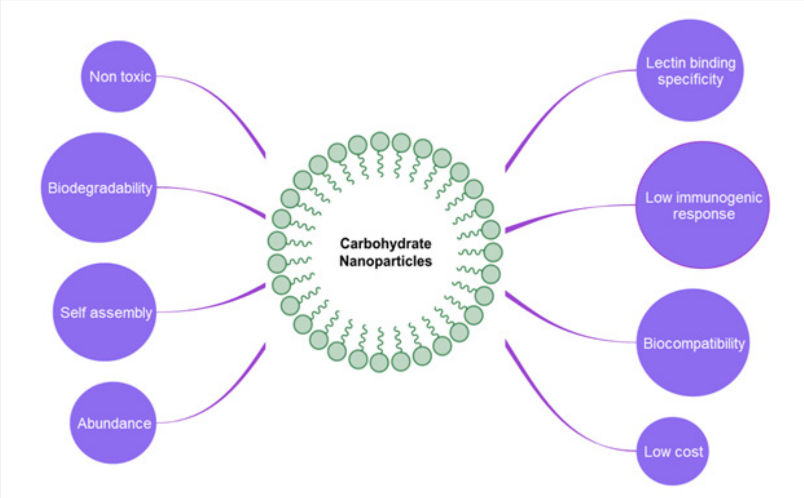

Figure 1: Characteristic features of Carbohydrate Nanoparticles.

Table 1: Biomedical application of carbohydrate-based nanoparticles.

Carbohydrate Type	Source	Biomedical application	Reference
Polysaccharide	Alginate-nanocellulose	Delivery of the drug Ibuprofen to be used as pain killer for multiple disorders	[7]
	Glycol chitosan	Photodynamic antitumor therapy via ROS sensitization	[8]
	Carboxymethyl tamarind kernel polysaccharide	Drug delivery in Ophthalmic diseases	[9]
	Angelica sinensis polysaccharide	hepatoma-targeted delivery of therapeutic drug doxorubicin for liver cancer	[10]
	Ginseng polysaccharides	Fluorescent labeling and study of immunomodulatory mechanism	[11]
	Chitosan	Bioimaging and killing of cancer cells	[12]
	Astragalus polysaccharide	Treatment of sepsis induced myocardial dysfunction via TLR4/NF-κB signaling pathway inhibition	[13]
	Carboxymethyl chitosan and oxidized alginate	Bone tissue engineering	[14]
Disaccharide	lactose, trehalose and sucrose	Delivery of antimicrobial peptide	[15]
	Sucrose and trehalose	Gene transfer and anticancer activity	[16]
Monosaccharide	Fructose	Clofarabine Drug delivery and bioimaging in tumor cells	[17]
	Rhamnose	Detection of IgM and IgG	[18]
	Galactose	Doxorubicin drug delivery for hepatocellular carcinoma	[19]
	Galactose	siRNA Delivery to Hepatocellular Carcinoma	[20]

Drug and Gene Delivery

In addition to their natural origin, biodegradability, and biocompatibility, the properties of hydrophilicity and the possibility of large-scale production, together with the option of chemical modification, makes the saccharide NPs an ideal carrier molecule. The saccharide-based NPs have been used as carrier molecules for a variety of bioactive compounds such as anticancer drugs and antimicrobials [21,22], with targeting and pharmacokinetic enhancement of drug molecules. Carbohydrate-based NPs have also been shown to be effective in intranasal drug delivery due to their ability to cross the blood-brain barrier. In addition, carbohydrate polymers have been found to enhance the brain's ability to absorb drugs. Their surface modification with

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endogenous chemicals such as folic acid enables site-specific delivery of the bioactive molecules [23]. Carbohydrate NPs are also used for gene delivery as non-viral vectors for the treatment of various diseases. Conventional viral vectors carry the risk of becoming pathogenic and the limited size of the gene to be delivered makes the saccharide NP a great alternative. The cationic NPs based on carbohydrate molecules can interact with negatively charged DNA molecules and protect them from degradation until they reach the site of action. Several carbohydrate based NPSs have been used for the successful delivery of therapeutic genes, such as short interfering RNA (siRNA), DNA, and microRNA (miRNA) [24].

Diagnosis

Since the carbohydrate molecules are used as surface antigens for various interactions, carbohydrate NPs find their use as biomarkers for the detection and diagnosis of various diseases. From tumor cells identification to the presence of pathogens and their antigens, even at very low levels, NPs have enabled their diagnosis at an early stage [25,26]. In addition, saccharide-based NPs are also used to detect diseases related to glycan biosynthesis, modification, and degradation, such as defects in carbohydrate-active enzyme (CAZyme) molecules, leading to Alzheimer's disease and diabetes [27].

Other Applications

Carbohydrate NPs are also used in bioimaging, where they are used to improve image contrast. The commonly used metal-based NPs have the disadvantage of being toxic or having low biocompatibility. Therefore, the conjugation of carbohydrate and these metals forming a carbohydrate-metal conjugate NP may have the advantage of increased biocompatibility and lower toxicity [28]. Since the extracellular matrix of the living organism contains glycan molecules, the carbohydrate-based NPs can mimic this matrix and have therefore been shown to be suitable for tissue engineering and regeneration. These glycan NPs mimic the ECM and provide the necessary environment for cell attachment, differentiation, and proliferation that is required to generate new tissue. These techniques have been successfully used for bone and cartilage tissue regeneration [29].

Conclusions

Considering the biological importance of carbohydrate molecules and the ability of saccharide NPs to mimic these carbohydrate components, several biomedical applications of these NPs are proposed. From the early diagnosis of various diseases to targeted delivery of therapeutic drugs and genes and improvement of pharmacokinetics of bioactive molecules, glycan NPs offer several advantages. Thus, these molecules are the future of medical sciences.

Competing Interests

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions Statement

AKV conceived of the presented idea and DC wrote the review.

Acknowledgement

The authors would like to thank the Department of Microbiology, Sikkim University, for providing the computational infrastructure and central library facilities for procuring references and plagiarism analysis (URKUND: Plagiarism Detection Software).

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