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Research Article

NANONEEDLE-BASED INTRACELLULAR DELIVERY: A COMPREHENSIVE REVIEW OF DRUG AND BIOMOLECULE DELIVERY STRATEGIES

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ABSTRACT

Intracellular delivery of drugs and biomolecules holds great promise for the development of targeted therapies and advanced biomedical applications. Nanoneedles, as emerging tools in nanomedicine, offer a unique approach for precise and efficient intracellular delivery. This comprehensive review aims to provide an overview of nanoneedle-based intracellular delivery strategies for drugs and biomolecules. It covers various aspects, including the design and fabrication of nanoneedles, mechanisms of cellular uptake, delivery routes, and applications in drug delivery, gene therapy, and cell manipulation. Furthermore, the review discusses the challenges and future directions in the field of nanoneedle-based intracellular delivery, highlighting the potential for clinical translation and impact on healthcare.

KEYWORDS

Nanoneedles, intracellular delivery, drug delivery, biomolecules, targeted therapy, nanomedicine, cellular uptake, gene therapy, cell manipulation, biomedical applications.

INTRODUCTION

Intracellular delivery of drugs and biomolecules is a crucial aspect of modern healthcare and biomedical research. It allows for precise targeting of specific cells and subcellular compartments, enabling effective treatment and manipulation of cellular processes. Nanoneedles have emerged as promising tools in the

field of nanomedicine for achieving efficient and controlled intracellular delivery. These nanoscale structures provide a means to penetrate cellular membranes and deliver therapeutic agents directly into the cytoplasm or specific organelles.

This comprehensive review aims to provide a comprehensive overview of nanoneedle-based intracellular delivery strategies for drugs and biomolecules. It explores the design and fabrication of nanoneedles, the mechanisms of cellular uptake, the various delivery routes employed, and the applications in drug delivery, gene therapy, and cell manipulation. By examining the advancements in nanoneedle technology, this review seeks to shed light on the potential of this approach for improving targeted therapies and biomedical applications.

METHOD

To conduct a comprehensive review of nanoneedle-based intracellular delivery strategies for drugs and biomolecules, the following methodology was employed:

Literature Search: A systematic search was conducted in relevant scientific databases, including PubMed, Scopus, and Web of Science. The search terms included combinations of keywords such as "nanoneedles," "intracellular delivery," "drug delivery," "biomolecules," "gene therapy," and "cell manipulation." The search was limited to articles published in the last 10 years to ensure inclusion of recent advancements.

Inclusion and Exclusion Criteria: Articles were screened based on their relevance to nanoneedle-based intracellular delivery strategies. Only articles written in English and focusing on the design, fabrication, mechanisms, delivery routes, applications, and challenges of nanoneedle-based intracellular delivery were included. Review articles, original research articles, and conference proceedings were considered for inclusion.

Data Extraction and Analysis: Relevant data from selected articles were extracted, including information on nanoneedle materials, fabrication techniques, cellular uptake mechanisms, delivery routes, applications, and challenges. The extracted data were organized and synthesized to identify common themes and trends in nanoneedle-based intracellular delivery strategies.

Evaluation and Quality Assessment: The quality and reliability of the included articles were assessed. The credibility of the studies, the robustness of the experimental methodologies, and the validity of the reported results were considered during the evaluation process.

Data Synthesis and Presentation: The extracted data were synthesized and presented in a coherent manner, highlighting the key findings, advancements, and challenges associated with nanoneedle-based intracellular delivery strategies. The information was organized into relevant sections, such as design and fabrication, mechanisms of cellular uptake, delivery routes, and applications.

Discussion and Interpretation: The synthesized data were critically analyzed and discussed to provide insights into the current state of nanoneedle-based intracellular delivery strategies. The advantages, limitations, and potential future directions of these strategies were explored. The discussion aimed to provide a comprehensive understanding of the field and identify gaps in knowledge.

By employing this methodological approach, the review provides a comprehensive overview of nanoneedle-based intracellular delivery strategies for drugs and biomolecules. It offers insights into the design, mechanisms, delivery routes, applications, and

challenges associated with this emerging field of research.

RESULTS

The review of nanoneedle-based intracellular delivery strategies for drugs and biomolecules reveals significant advancements and promising outcomes in the field. Several key findings and outcomes are discussed below:

Design and Fabrication of Nanoneedles: Various materials and fabrication techniques have been utilized to develop nanoneedles with desirable properties such as biocompatibility, mechanical strength, and precise dimensions. These include silicon-based nanoneedles, polymer-based nanoneedles, and carbon nanotubes. The design of nanoneedles also considers factors such as needle length, diameter, surface modifications, and functionalization for efficient delivery.

Mechanisms of Cellular Uptake: Nanoneedles utilize different mechanisms for cellular uptake, including direct penetration, endocytosis, and electroporation. The choice of mechanism depends on the properties of the nanoneedles and the target cells. Understanding the cellular uptake mechanisms is crucial for optimizing intracellular delivery efficiency.

Delivery Routes and Applications: Nanoneedle-based intracellular delivery has shown promising applications in drug delivery, gene therapy, and cell manipulation. Drug-loaded nanoneedles can deliver therapeutic agents directly into cells, bypassing extracellular barriers and enhancing the efficacy of treatments. Gene delivery using nanoneedles allows for precise targeting of specific cells and tissues, facilitating gene editing and modulation of cellular functions. Nanoneedles also enable cell manipulation, such as

intracellular sensing and probing, which aids in studying cellular processes and diagnosing diseases.

DISCUSSION

The discussion highlights the advantages and challenges associated with nanoneedle-based intracellular delivery strategies. Nanoneedles offer several advantages, including high delivery efficiency, precise targeting, and minimal cytotoxicity. They provide a platform for personalized medicine and tailored treatments. However, challenges such as scalability, biocompatibility, long-term stability, and regulatory considerations need to be addressed for successful translation into clinical applications. Furthermore, the review discusses the importance of optimizing the design, fabrication, and functionalization of nanoneedles to improve their performance and address specific therapeutic requirements.

CONCLUSION

Nanoneedle-based intracellular delivery holds tremendous potential for revolutionizing drug delivery, gene therapy, and cell manipulation. The comprehensive review reveals the significant progress made in this field, showcasing the versatility and effectiveness of nanoneedles in delivering drugs and biomolecules to target cells and organelles. Further research and development efforts are needed to overcome the existing challenges and ensure the clinical translation of nanoneedle-based intracellular delivery strategies. With continued advancements, nanoneedles have the potential to play a transformative role in improving targeted therapies and advancing biomedical applications, ultimately benefiting patients and healthcare outcomes.

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