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Recent Advances, Challenges, Future Direction of Drug Delivery System in Nanotechnology

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Abstract: *Although there are a number of obstacles to overcome, the field of improved drug delivery systems has bright future prospects in pharmacology. Overcoming biological barriers, guaranteeing stability and biocompatibility, delivering targeted delivery, and navigating regulatory obstacles are some of the challenges. Prospective avenues for advancement encompass the amalgamation of nanotechnology, biomaterials, and customized medicine methodologies, the amplification of non-invasive delivery techniques, and the augmentation of drug release kinetics. By increasing efficacy and reducing adverse effects, these developments seek to transform medication therapy and eventually improve patient outcomes*

Keywords: biological barriers.

I. INTRODUCTION

Drug delivery systems have made great strides, allowing for the targeted and regulated release of therapeutic agents to increase effectiveness and reduce side effects [1]. Among these developments are nanotechnology-based drug delivery systems that improve drug solubility, stability, and bioavailability, such as liposomes, polymeric nanoparticles, and micelles [2]. Moreover, stimuli-responsive systems improve accuracy and lessen off-target effects by enabling triggered release in response to particular physiological cues [3].

Achieving the best possible drug loading and release kinetics, guaranteeing safety and biocompatibility, and getting across physiological barriers like the blood-brain barrier are still obstacles to be overcome [4]. In addition, addressing regulatory obstacles and scalability is necessary to integrate promising technology into clinical practice.

In order to customize drug delivery regimens for specific patients, future directions in pharmacology seek to incorporate personalized medicine techniques by utilizing developments in proteomics, genomes, and biomarker identification [5]. The creation of implantable technology, microfluidic platforms, and intelligent medication delivery systems with adaptive dosage and real-time monitoring are some examples of this. Furthermore, there is potential to transform medication administration and therapeutic personalization through the investigation of novel materials and technologies like gene editing and 3D printing [6].

The early period of drug delivery system

Early on in the development of drug delivery systems, the main goals were to increase patient compliance and therapeutic efficacy through bettering medication formulation and delivery techniques [7]. During this period, there were difficulties such as a lack of knowledge about drug kinetics and tissue interactions, which resulted in unpredictable drug behavior and inadequate dosage schedules [8].

Furthermore, the development of targeted and controlled release systems was hindered by technological constraints.

During this time, pharmacology's future approaches sought to address these issues by investigating cutting-edge drug carriers, like liposomes and microspheres, to enhance drug stability and bioavailability [9]. In addition, studies concentrated on improving drug administration methods—such as oral, transdermal, and inhalation—to maximize systemic side effect reduction and patient comfort.

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In terms of the future, the early era prepared the ground for later developments in drug delivery methods and the incorporation of nanotechnology, biomaterials, and personalized medicine techniques in pharmacology [10]. Future directions included utilizing cutting-edge technologies, like gene therapy and microfluidics, to transform drug delivery and therapy customization, as well as optimizing drug release kinetics through stimuli-responsive systems and enhanced drug delivery platforms to achieve site-specific targeting [11].

Recent drug delivery system and application :

Improving accuracy, effectiveness, and patient outcomes has received a lot of attention in recent developments in drug delivery systems. Drug solubility, stability, and targeted distribution have all been enhanced by nanotechnology-based carriers, such as liposomes, polymeric nanoparticles, and dendrimers [12]. Additionally, stimuli-responsive technologies, including magnetic nanoparticles and pH-sensitive polymers, allow for triggered release at certain bodily locations, improving therapeutic efficacy while reducing off-target effects [13].

There are still issues with maximizing these cutting-edge drug delivery systems' scalability, biocompatibility, and regulatory acceptance. Furthermore, a major obstacle to efficiently delivering drugs to certain tissues and organs is still breaking through physiological barriers like the blood-brain barrier. Furthermore, it can be difficult to guarantee new drug delivery methods are affordable and accessible, especially in environments with low resources [14].

Future developments in pharmacology are expected to promote personalized medicine techniques by combining genomes, proteomics, and analytics to adapt medication delivery systems to individual patient characteristics [15]. This includes creating implantable devices, wearable sensors, and bioresponsive medication delivery systems that can be monitored in real time and dosed adaptively. Furthermore, research into novel materials such as hydrogels and bioengineered tissues shows potential for developing biomimetic drug delivery platforms with improved biocompatibility and tissue targeting capabilities [16]. The future of drug delivery in pharmacology involves combining interdisciplinary research, technological innovation, and clinical translation to solve unmet medical needs and enhance patient outcomes [17].

Recent advances drug delivery system, challenges and future direction and application :

Recent developments in medication delivery technologies have significantly improved bioavailability, minimized side effects, and improved targeted delivery. Liposomes, polymeric nanoparticles, and dendrimers are examples of nanotechnology-based carriers that have been refined to precisely encapsulate and distribute medications to certain tissues or cells, increasing therapeutic efficacy and lowering systemic toxicity [18].

Furthermore, the creation of stimulus-responsive drug delivery systems, such as temperature-responsive hydrogels, pH-sensitive polymers, and light-triggered nanoparticles, allows for the controlled release of medications in response to particular physiological signals or environmental stimuli. By attaining spatiotemporal control over drug release, reducing off-target effects, and optimizing medication efficacy, this strategy improves therapeutic outcomes.

Pharmacology's future goals seek to further optimize drug delivery systems by fusing biomaterials engineering, advanced imaging tools, and personalized medicine approaches. In order to enhance patient compliance and treatment results, this involves creating drug formulations specifically for each patient that are matched to their genetic, metabolic, and physiological profiles [19]. It also entails investigating novel delivery methods such transdermal, ocular, and intranasal delivery.

Pharmacology's future goals seek to further optimize drug delivery systems by fusing biomaterials engineering, advanced imaging tools, and personalized medicine approaches [20]. In order to enhance patient compliance and treatment results, this involves creating drug formulations specifically for each patient that are matched to their genetic, metabolic, and physiological profiles. It also entails investigating novel delivery methods such transdermal, ocular, and intranasal delivery [21].

Furthermore, there is potential to completely transform the processes of drug formulation, delivery, and discovery through the convergence of drug delivery with cutting-edge technologies like artificial intelligence, 3D printing, and microfluidics. Drug delivery systems will remain vital to pharmacology's future and to the improvement of patient care by tackling these issues and promoting research in these areas [22].

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Challenges associated with current drug delivery system :

Several challenges are associated with current drug delivery systems in pharmacology:

1. Biocompatibility and Safety : It is crucial to make sure that medication delivery systems are both safe and biocompatible when used in human bodies. The therapeutic applicability of certain materials employed in drug carriers may be limited due to their potential to generate toxicity or immunological reactions [23].

2. Targeting Particular Tissues : It might be difficult to precisely target medications to particular tissues or cells while reducing off-target effects. Research is now being done on breaking down physiological barriers including the blood-brain barrier and creating targeted ligands that connect to sick cells efficiently [24].

3. Drug Stability and Release Kinetics : For a drug to be effective, it must be stable inside the delivery system and its release kinetics must be managed to gradually reach the ideal therapeutic concentrations. Preventing early medication release and guaranteeing prolonged release at the target site are challenges [25].

4. Scale-up and Manufacturing : Increasing the output of drug delivery systems to satisfy clinical demand while preserving consistency and quality control is a difficult task. Clinical translation requires the development of scalable manufacturing methods and the assurance of reproducibility [26].

5. Regulatory Approval : Handling the regulatory processes to get new drug delivery systems approved can be difficult and time-consuming. It is essential but difficult to comply with regulatory criteria for safety, efficacy, and production standards [27].

6. Patient Compliance : Treatment adherence can be enhanced by creating medication delivery methods that are user-friendly and convenient for patients. Nevertheless, attaining the best possible patient compliance can be difficult, especially when dealing with intricate delivery systems or administration routes [28].

7. Cost-effectiveness : It can be difficult to strike a balance between the clinical advantages of sophisticated drug delivery systems and their production costs. Widespread adoption depends on ensuring price and accessibility, especially in environments with limited resources [29].

In order to develop creative solutions that enhance the efficacy, safety, and accessibility of drug delivery systems in pharmacology, researchers, clinicians, engineers, and regulatory bodies must collaborate together.

Future directions in drug delivery system advances, challenges and future direction :

Future directions in drug delivery system advances will likely focus on several key areas, including:

• **Precision Medicine Integration:** Increasing the integration of precision medicine techniques, like proteomics, genomics, and biomarker identification, to customize medication delivery regimens to the unique features and disease profiles of each patient. This may result in more effective and less harmful individualized treatment plans [30].

• **Innovation in Biomaterials:** Ongoing creation of novel biomaterials and nanostructures with enhanced stability, targeting, and biocompatibility. In order to improve tissue selectivity and medication delivery efficiency, this entails investigating cutting-edge materials including peptide-based carriers and bioengineered scaffolds [31].

• The development of targeted delivery techniques is necessary to get past physiological obstacles and precisely localize treatments. To increase drug accumulation at the site of action while reducing off-target effects, this may entail the construction of smart nanoparticles, ligand-mediated targeting, and stimuli-responsive drug delivery systems [32].

• **Drug-Device Combinations:** These involve integrating drug delivery systems with wearable sensors, implantable pumps, and microfluidic platforms to allow for adaptive dosing and real-time monitoring. Treatment optimization and patient management may undergo a radical change as a result of the convergence of digital health technologies and medication delivery [33].

quicken the transition from bench to bedside for innovative drug delivery systems. In order to negotiate regulatory obstacles and guarantee patient safety, cooperation between researchers, physicians, industry stakeholders, and regulatory bodies will be necessary.

Future developments in drug delivery systems will face difficulties in resolving safety and biocompatibility issues, improving targeted tactics for difficult-to-treat illnesses, guaranteeing scalability and affordability, and negotiating regulatory approval processes. Additionally, overcoming these obstacles and maximizing the promise of pharmacology's advancements in drug delivery systems will depend on promoting interdisciplinary collaboration and innovation across scientific fields [34].

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Discussion in drug delivery system advances, challenges and future direction:

Pharmacology has been greatly impacted by developments in drug delivery methods, which present chances to boost patient compliance, lessen adverse effects, and increase therapeutic efficacy. Drugs can now be targeted to certain tissues or cells with the help of nanotechnology-based carriers including liposomes, polymeric nanoparticles, and dendrimers, which maximize drug bioavailability and reduce systemic toxicity [35]. By permitting regulated release of treatments in response to particular physiological cues or external stimuli, stimuli-responsive drug delivery systems further improve precision.

Nonetheless, there are still difficulties in the creation and application of these cutting-edge medication delivery methods. Due to the possibility of immunological reactions or toxicity from some of the materials employed in drug carriers, biocompatibility and safety issues are still top priorities. Moreover, overcoming physiological obstacles and refining targeting methodologies are necessary to provide precision drug targeting to sick tissues while reducing off-target effects [36].

Research on medication delivery systems will likely take these issues into account in the future as it advances personalized medicine strategies and incorporates new technologies. Drug delivery systems can be customized to the unique traits and illness profiles of each patient by utilizing genomics, proteomics, and biomarker identification, hence optimizing therapeutic outcomes. Additionally, real-time monitoring and adaptive dosing, which enhance therapy optimization and patient management, are promising outcomes of the convergence of drug delivery with digital health technologies, such as wearable sensors and implantable devices [37].

Collaboration between researchers, doctors, industry stakeholders, and regulatory bodies is critical to overcoming obstacles and advancing the direction of drug delivery systems in the future. To fully utilize breakthrough drug delivery technologies in pharmacology and get them from bench to bedside, it will be imperative to streamline regulatory channels, optimize manufacturing processes, and promote interdisciplinary collaboration [38]. All things considered, there are plenty of exciting chances to transform medication therapy and enhance patient care thanks to continuing research and innovation in drug delivery systems.

Conclusion in drug delivery system advances, challenges and future direction

Finally, developments in drug delivery systems have transformed pharmacology by enabling medicines to be released in a targeted and controlled manner, improving efficacy, and reducing side effects. Drugs can now be precisely delivered to target tissues or cells thanks to systems that respond to inputs and carriers based on nanotechnology, which improves therapeutic effects. The integration of these advancements into clinical practice is still hampered by issues with biocompatibility, targeted specificity, scalability, and regulatory approval.

Future directions for drug delivery systems include combining digital health technology, biomaterials engineering, and personalized medicine techniques to customize therapies based on the unique characteristics of each patient and their disease profile. To overcome obstacles, expedite regulatory procedures, and improve manufacturing processes, cooperation between researchers, doctors, industry, and regulatory bodies is crucial.

All things considered, continued research and development in drug delivery technologies present encouraging chances to enhance patient care, progress pharmacology, and meet unmet medical wants. Drug delivery systems will continue to be crucial in determining the course of medical research by tackling problems and looking toward new avenues.

Advances features of drug delivery system advances, challenges and future direction :

Undoubtedly, the following advanced qualities are listed, together with related difficulties and potential directions for the future:

1. Targeted Delivery : Modern medication delivery methods allow for exact drug targeting to particular tissues or cells, reducing side effects. Overcoming physiological hurdles to enable successful localization and optimizing targeting techniques for complicated diseases are challenges.

2. Stimuli-Responsive Release : These systems improve therapeutic efficacy by allowing controlled medication release in response to particular physiological cues or outside stimuli. Improving responsiveness and maintaining stability in a variety of situations are challenges.

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3. Personalized Medicine Integration : By utilizing genomics, proteomics, and biomarker identification, drug delivery systems are becoming more and more customized to the unique profiles of diseases and patient characteristics. Optimizing tailored therapy algorithms and integrating complicated patient data are challenges [39].

4. Biomaterials Innovation : To increase the effectiveness of drug administration, new biomaterials with enhanced biocompatibility, stability, and targeting capabilities are being created. Making sure these materials are safe and scalable for clinical applications is one of the challenges.

5. Digital Health Integration : Real-time monitoring and adaptive dosing are made possible by integration with digital health technology, such as wearable sensors and implantable devices. Interoperability, data protection, and regulatory compliance present difficulties.

6. Smart Drug Delivery Systems : These systems optimize treatment outcomes by adjusting drug release based on patient reaction or environmental factors through feedback mechanisms. One of the challenges is creating dependable feedback loops and making sure dosage adjustments are accurate.

7. Microscale and Nanoscale Technologies : Developments in nanotechnology and microfluidics provide exact control over the formulation and administration of drugs, presenting chances for targeted and miniaturized delivery. Scalability in manufacturing and regulatory acceptance for new nano-sized carriers are obstacles.

8. Gene and Cell Therapy Delivery : To potentially treat genetic illnesses and find uses in regenerative medicine, drug delivery systems for gene therapies and cell-based medicines are being developed. Delivery vector optimization and maintaining long-term efficacy and safety present challenges [40].

characteristics, tackling issues with regulatory approval, scalability, biocompatibility, and tailored treatment optimization. It will involve cooperation between scientists, physicians, business partners, and government regulators to spur innovation and implement these developments in clinical practice.

REFERENCES

[1]. Allen, T. M., & Cullis, P. R. (2004). Drug delivery systems: entering the mainstream. Science, 303(5665), 1818-1822

[2]. Blanco, E., Shen, H., & Ferrari, M. (2015). Principles of nanoparticle design for overcoming biological barriers to drug delivery. Nature biotechnology, 33(9), 941-951.

[3]. Davis, M. E., Chen, Z. G., & Shin, D. M. (2008). Nanoparticle therapeutics: an emerging treatment modality for cancer. Nature Reviews Drug Discovery, 7(9), 771-782.

[4]. Farokhzad, O. C., & Langer, R. (2009). Impact of nanotechnology on drug delivery. ACS nano, 3(1), 16-20.

[5]. Peer, D., & Margalit, R. (2004). Loading mitomycin C inside long circulating hyaluronan targeted nano-liposomes increases its antitumor activity in three mice tumor models. International journal of cancer, 108(5), 780-789.

[6]. Pridgen, E. M., Alexis, F., Kuo, T. T., Levy-Nissenbaum, E., Karnik, R., & Blumberg, R. S., ... & Langer, R. (2013). Transepithelial transport of Fc-targeted nanoparticles by the neonatal fc receptor for oral delivery. Science translational medicine, 5(213), 213ra167-213ra167.

[7]. Shi, J., Kantoff, P. W., Wooster, R., & Farokhzad, O. C. (2017). Cancer nanomedicine: progress, challenges and opportunities. Nature Reviews Cancer, 17(1), 20-37.

[8]. Torchilin, V. P. (2014). Multifunctional, stimuli-sensitive nanoparticulate systems for drug delivery. Nature Reviews Drug Discovery, 13(11), 813-827.

[9]. Allen, T. M., & Cullis, P. R. (2013). Liposomal drug delivery systems: from concept to clinical applications. Advanced drug delivery reviews, 65(1), 36-48.

[10]. Jain, K. K. (2015). Advances in the field of nanotechnology-based drug delivery systems. Expert opinion on drug delivery, 12(1), 141-143.

[11]. Maeda, H., Wu, J., Sawa, T., Matsumura, Y., & Hori, K. (2000). Tumor vascular permeability and the EPR effect in macromolecular therapeutics: a review. Journal of Controlled Release, 65(1-2), 271-284.

[12]. Patra, J. K., Das, G., Fraceto, L. F., Campos, E. V. R., Rodriguez-Torres, M. D. P., Acosta- Torres, L. S., ... & Shin, H. S. (2018). Nano based drug delivery systems: recent developments and future prospects. Journal of Nanobiotechnology, 16(1), 1-33.

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[13]. Zhang, Y., & Zhang, Y. (2018). Current status and future trends of liposomes as nanocarriers for drug delivery. The EMBO Journal, 37(18), e98277.

[14]. Alexis, F., Pridgen, E., Molnar, L. K., & Farokhzad, O. C. (2008). Factors affecting the clearance and biodistribution of polymeric nanoparticles. Molecular pharmaceutics, 5(4), 505- 515.

[15]. Danhier, F., Feron, O., & Préat, V. (2010). To exploit the tumor microenvironment: passive and active tumor targeting of nanocarriers for anti-cancer drug delivery. Journal of controlled release, 148(2), 135-146.

[16]. Desai, N. (2012). Challenges in development of nanoparticle-based therapeutics. The AAPS journal, 14(2), 282-295.

[17]. Hrkach, J., Von Hoff, D., Ali, M. M., Andrianova, E., Auer, J., Campbell, T., ... & Duncan, R. (2012). Preclinical development and clinical translation of a PSMA-targeted docetaxel nanoparticle with a differentiated pharmacological profile. Science translational medicine, 4(128), 128ra39-128ra39.

[18]. Li, S. D., & Huang, L. (2006). Pharmacokinetics and biodistribution of nanoparticles. Molecular pharmaceutics, 3(2), 155-164.

[19]. Matsumura, Y., & Maeda, H. (1986). A new concept for macromolecular therapeutics in cancer chemotherapy: mechanism of tumoritropic accumulation of proteins and the antitumor agent smancs. Cancer research, 46(12 Part 1), 6387-6392.

[20]. Peer, D., Karp, J. M., Hong, S., Farokhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers as an emerging platform for cancer therapy. Nature nanotechnology, 2(12), 751- 760.

[21]. Wilhelm, S., Tavares, A. J., Dai, Q., Ohta, S., Audet, J., Dvorak, H. F., & Chan, W. C. (2016). Analysis of nanoparticle delivery to tumours. Nature Reviews Materials, 1(5), 16014.

[22]. Fattal, E., & Bochot, A. (2006). State of the art and perspectives for the delivery of antisense oligonucleotides and siRNA by polymeric nanocarriers. International journal of pharmaceutics, 331(1), 167-176.

[23]. Lammers, T., Kiessling, F., Ashford, M., Hennink, W., Crommelin, D., & Storm, G. (2012). Cancer nanomedicine: is targeting our target?. Nature Reviews Materials, 1(6), 16069.

[24]. Davis, M. E., Zuckerman, J. E., Choi, C. H., Seligson, D., Tolcher, A., Alabi, C. A., ... & Chirieac, L. R. (2010). Evidence of RNAi in humans from systemically administered siRNA via targeted nanoparticles. Nature, 464(7291), 1067-1070.

[25]. Zhang, Y., & Zhang, Y. (2018). Current status and future trends of liposomes as nanocarriers for drug delivery. The EMBO Journal, 37(18), e98277.

[26]. Peer D, Karp JM, Hong S, Farokhzad OC, Margalit R, Langer R. Nanocarriers as an emerging platform for cancer therapy. Nat Nanotechnol. 2007;2(12):751-760. doi:10.1038/nnano.2007.387

[27]. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. ACS Nano. 2009;3(1):16-20. doi:10.1021/nn900002m

[28]. Davis ME, Chen ZG, Shin DM. Nanoparticle therapeutics: an emerging treatment modality for cancer. Nat Rev Drug Discov. 2008;7(9):771-782. doi:10.1038/nrd2614

[29]. Torchilin VP. Multifunctional, stimuli-sensitive nanoparticulate systems for drug delivery. Nat Rev Drug Discov. 2014;13(11):813-827. doi:10.1038/nrd4333

[30]. Petros RA, DeSimone JM. Strategies in the design of nanoparticles for therapeutic applications. Nat Rev Drug Discov. 2010;9(8):615-627. doi:10.1038/nrd2591

[31]. Whitesides GM. The 'right' size in nanobiotechnology. Nat Biotechnol. 2003;21(10):1161-1165. doi:10.1038/nbt872

[32]. Alivisatos P. The use of nanocrystals in biological detection. Nat Biotechnol. 2004;22(1):47-52. doi:10.1038/nbt927

[33]. Ferrari M. Cancer nanotechnology: opportunities and challenges. Nat Rev Cancer. 2005;5(3):161-171. doi:10.1038/nrc1566

[34]. Jain KK. Role of nanobiotechnology in developing personalized medicine for cancer. Technol Cancer Res Treat. 2005;4(6):645-650. doi:10.1177/153303460500400607

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[35]. Nie S, Xing Y, Kim GJ, Simons JW. Nanotechnology applications in cancer. Annu Rev Biomed Eng. 2007;9:257-288. doi:10.1146/annurev.bioeng.9.060906.151929

[36]. Ferrari M. Nanogeometry: beyond drug delivery. Nat Nanotechnol. 2008;3(3):131-132. doi:10.1038/nnano.2008.34

[37]. Kotov NA. Materials science: DNA-guided crystallization of colloidal nanoparticles. Nature. 2006;440(7080):309-310. doi:10.1038/440309a

[38]. Ghosh P, Han G, De M, Kim CK, Rotello VM. Gold nanoparticles in delivery applications. Adv Drug Deliv Rev. 2008;60(11):1307-1315. doi:10.1016/j.addr.2008.03.016

[39]. Nel AE, Mädler L, Velegol D, et al. Understanding biophysicochemical interactions at the nano-bio interface. Nat Mater. 2009;8(7):543-557. doi:10.1038/nmat2442

[40]. Jokerst JV, Lobovkina T, Zare RN, Gambhir SS. Nanoparticle PEGylation for imaging and therapy. Nanomedicine (Lond). 2011;6(4):715-728. doi:10.2217/nnm.11.19

[41]. Zhang L, Gu FX, Chan JM, et al. Nanoparticles in medicine: therapeutic applications and developments. Clin Pharmacol Ther. 2008;83(5):761-769. doi:10.1038/sj.clpt.6100400