Applications of capillary action in drug delivery

Xiaosi Li

Yue Zhao

Chao Zhao

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Review

Applications of capillary action in drug delivery

Xiaosi Li,[1,3] [2,3] [1,*]

SUMMARY

Contrary to the fact that capillary action is ubiquitous in our daily lives, its role in drug delivery has not attracted attention. Therefore, its application in medicine and disease treatment has not been actively developed. This perspective begins by reviewing the principles, advantages, and limitations of the three existing drug delivery strategies: non-covalent interaction, cavity loading, and covalent conjugation. Then, we discussed the principle of capillary action in drug delivery and the influencing factors that determine its performance. To illustrate the advantages of capillary action over existing drug delivery strategies and how the capillary action could potentially address the shortcomings of the existing drug delivery strategies, we described five examples of using capillary action to design drug delivery platforms for disease treatment: marker pen for topical and transdermal drug delivery, microneedle patch with a sponge container for pulsatile drug delivery, core-shell scaffold for sustained release of growth factors, oral bolus for insulin delivery to the esophagus, and semi-hollow floating ball for intravesical and gastroprotective drug delivery. Each of the five drug delivery platforms exhibits certain unique functions that existing drug delivery technologies cannot easily achieve, hence expected to solve specific practical medical problems that are not satisfactorily resolved. As people pay more attention to capillary action and develop more drug delivery platforms, more unique functions and characteristics of capillary action in drug delivery will be explored. Thus, capillary action could become an important choice for drug delivery systems to improve therapeutic drug efficacy, treat diseases, and improve human health.

INTRODUCTION

Li et al., 2019 Tiwari et al., 2012 Wen et al., 2015

Li et al., 2020 Lu et al., 2016 Wang et al., 2019 Zhao et al., 2013

Bulbake et al., 2017 Shomorony et al., 2019 Sorenson and Chesnut, 2019 van Eerden et al., 2020

Mei et al., 2014 Mitropoulos, 2009

czhao15@eng.ua.edu

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EXISTING STRATEGIES FOR DRUG DELIVERY

Non-covalent interactions

Wei et al., 2017

Georgakilas et al., 2016 Karshikoff, 2006 Weldon et al., 2019

Jadhav et al., 2006 Kajbafvala and Salabat, 2017 Malik et al., 2012 Sah and Sah, 2015

Ong et al., 2016

Li et al., 2020

Sah and Sah, 2015 Shim and Sah, 2020

Abraham et al., 2020 Kaasalainen et al., 2015 Kumar and Sharma, 2020 Liu et al., 2018 Mauri et al., 2017 Sims et al., 2020 Xiao et al., 2013 Zhao et al., 2012

Nayerossadat et al., 2012 Sung and Kim, 2019 Zhang et al., 2016

Fröhlich, 2012

Cavity loading

Li et al., 2020 Shomorony et al., 2019 Wang et al., 2019

Lin et al., 2013 Rwei et al., 2015 Timko et al., 2014 Zhan et al., 2016 2017 Rwei et al., 2017 Yan et al., 2013

Rwei et al., 2015 Shomorony et al., 2019 Zhan et al., 2016 2017

Liu et al., 2018 Rwei et al., 2015 Shomorony et al., 2019 Zhan et al., 2016 2017

Liu et al., 2018 Rwei et al., 2015 Shomorony et al., 2019 Zhan et al., 2016 2017

Covalent conjugation

Zhang et al., 2020 Zhao et al., 2019

activity but capable of releasing the active drug in the body by enzymatic reaction or chemical reaction or a combination of both (Rautio et al., 2018

Zhao et al., 2019

CHALLENGES IN DRUG DELIVERY

Biocompatibility of materials

Sundar et al., 2016

Marin et al., 2013

Li et al., 2020

Zhao et al., 2020

Zhang et al., 2016
Shomorony et al., 2019
Zhang et al., 2020 Zhao et al., 2019

Insufficient drug encapsulation efficiency and drug waste

Nii and Ishii, 2005 Rwei et al., 2015

Shomorony et al., 2019 Zhan et al., 2016 2017

Nii and Ishii, 2005

Insufficient drug release control

Abdo et al., 2020 Shomorony et al., 2019

Kohane et al., 1998b Shomorony et al., 2019

systems. Zero-order drug delivery refers to the process of a constant drug released per unit time from a carrier. It is particularly desired for potent drugs because it can precisely maintain constant plasma drug levels so that the drug's therapeutic effects can be maximized, and the toxic effects can be minimized (Zhao et al., 2017

Jain

et al., 2011

Dang et al., 2017

Rwei et al., 2017

Low drug bioavailability for oral drug delivery system

Bruno et al., 2013 Homayun et al., 2019 Renukuntla et al., 2013

Renukuntla et al., 2013

Renukuntla et al., 2013

CAPILLARY ACTION IN DRUG DELIVERY

Principle of capillary action in drug loading and controlled release

Capillary action retains the liquid to encapsulate and store drugs

Figure 1

Capillary action transfers the liquid to deliver and release drugs

Figure 1

Figure 1. Principles of capillary action in drug loading and controlled release

Factors affecting the roles of capillary action in drug loading and controlled release

Surface-to-volume ratio of the material

The polarity of the surface

Besides, surface polarity can accelerate the release of the drug because the liquid is easier to wet and pass through the surface.

Nature of the liquid

Temperature

Predictive design of drug delivery platforms based on capillary action

Marker pen for high drug encapsulation and zero-order drug release

Figure 2

Li et al., 2021

Use a marker pen to tame tetrodotoxin (TTX) for local anesthesia.

Figure 2. A schematic diagram of the marker pen as a platform for drug encapsulation and topical and transdermal drug delivery

action potentials of neurons (Kohane et al., 1998b

Liu et al., 2018 Zhao et al., 2019

Shomorony et al., 2019

Liu et al., 2018

Zhao et al., 2019

desired small amount of TTX. Thus, the marker pen can maintain the local concentration of TTX higher than the effective concentration but lower than the toxic level.

TTX-filled marker pen can be used as a local anesthetic for chronic skin pain management in patients with skin disorders. The patient or clinician can use the pen to apply TTX on the skin surface that needs pain relief. It may be necessary to deliver the CPEs along with TTX in pen to improve the permeability of TTX through the skin. A TTX-filled marker pen is a safe and on-demand approach to relieve local pain, allowing patients to control the time, intensity, and duration of anesthesia according to their changing needs and conditions. Thus, greatly improving patients' quality of life with chronic skin pain and reducing or obviating opioids use.

Marker pen for topical antibiotics.

Yang et al., 2016

Hoberman et al., 2011

Yang et al., 2016

Microneedle patch with a sponge container for pulsatile drug delivery

Kim et al., 2012 Li et al., 2017

Figure 3

Microneedle patch for cardiac repair.

Wang et al., 2017

Tang et al., 2018

Figure 3. A schematic diagram of the microneedle patch with a sponge container to achieve pulsatile drug delivery for cardiac repair after acute myocardial infarction (MI) and on-demand local anesthesia

Microneedle patch for on-demand local anesthesia.

Bagshaw et al., 2015

Kohane et al., 1998a

Core-shell scaffold for sustained release of GF

Blackwood et al., 2012 Oliveira et al., 2021

Blackwood et al., 2012

Figure 4. A schematic diagram of the core-shell scaffold for sustained release of GF

Here, we introduced the core-shell scaffold as a drug delivery platform to achieve sustained release of BMPs. The scaffold consists of two parts: the inner core and outer shell. The inner core can be a collagen scaffold, a super-absorbent sponge, or a hydrogel. The inner core absorbs the drug solution and stores it. The outer shell comprises dense fibers or a solid shell with microchannels (Figure 4

Oral bolus to deliver insulin to the esophagus

Han et al., 2020

Figure 5

Abramson et al., 2019a 2019b

Semi-hollow floating ball for intravesical and gastroprotective drug delivery

Figure 5. A schematic diagram of the bolus to deliver peptide and protein drugs to the esophagus

long-term gastric retention up to 24 hr or longer(Bhadouriya et al., 2011 Zhao et al., 2021

Figure 6

CONCLUSION AND OUTLOOK

Figure 6. A schematic diagram of the semi-hollow floating ball for intravesical and gastroprotective drug delivery

capillary action in drug delivery has not attracted people's attention. Therefore, its role has not been actively developed. The basic principle of capillary action in drug delivery is that the material can hold the liquid by capillary action, so the drug dispersed or dissolved in the liquid can be encapsulated in the materials. The materials can transfer liquid on the surface so that they can deliver and release drugs. Many factors affect the capillary action's performance in drug encapsulation efficiency and release kinetics, such as the surface-to-volume ratio, surface polarity, nature of the liquid, and temperature. Understanding these factors and their effects can help maximize their role in drug delivery. By adjusting these factors, the drug loading capacity (how the liquid is absorbed into the material) and drug release profile (the speed at which the liquid passes through the material) of the drug delivery system can be regulated to meet the actual needs of specific disease treatment.

We introduced five prospective designs of drug delivery platforms based on capillary action: marker pen for topical and transdermal drug delivery, microneedle patch with a sponge container for pulsatile drug delivery, core-shell scaffold for sustained release of GF, oral bolus for insulin delivery to the esophagus, and semi-hollow floating ball for intravesical and gastroprotective drug delivery. As shown by these platforms, capillary action exhibits many unique characteristics that existing drug delivery technologies cannot easily achieve. Therefore, capillary action can solve some limitations of existing drug delivery systems, such as (i) achieve a high drug encapsulation with almost no drug wastage; (ii) achieve zero-order, pulsatile, and on-demand drug release; (iii) increase the bioavailability of drugs; (iv) can be green with no issue of the solvent residue because the process of drug loading and drug release does not involve organic solvents. These five platforms can be used to treat different diseases, such as pain management, skin infection treatment, heart regeneration, bond repair, and diabetes medication. As people pay more attention to the application of capillary action in drug delivery, many other drug delivery platforms based on capillary action are expected to be developed with unique functions. Capillary action could become an important choice for designing drug delivery systems to improve therapeutic drug efficacy, treat diseases, and ultimately improve human health.

Capillary action combined with other drug delivery strategies is suitable for water-soluble and poorly water-soluble drugs. For example, poorly water-soluble drugs can be covalently conjugated with hydrophilic polymers to improve their water affinity. The synthesized prodrug can be loaded into the drug delivery systems by capillary action. Drugs can be formulated into polymeric or inorganic particles through non-covalent interactions and cavity loading. When the obtained particles are uniformly dispersed in water, the drug therein can be encapsulated and released by capillary action.

As interdisciplinary research, the development of new drug delivery strategies requires new molecules, technologies to manufacture these molecules into new materials with designed structures, and corresponding characterization methods for evaluating the structure and function of the molecules and materials. Therefore, the development of drug delivery technology will promote the development of materials science, chemistry, chemical engineering, biomedical engineering, and other related fields.

Limitations of the study

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AUTHOR CONTRIBUTIONS

DECLARATION OF INTERESTS

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