NATURALISTA CAMPANO
ISSN: 1827-7160
Volume 28 Issue 1, 2024

Textile-Based Drug Delivery Systems: Microneedles and Textile Materials

Dr. S. Jayapriya[1], Dr. S. N. Suresh[2]

[1]Associate Professor and Head, Department of Costume Design and Fashion, Nehru Arts and Science College, Coimbatore - 641105, Tamil Nadu, India.
[2]Associate Professor, Department of Biotechnology, Rathinam College of Arts and Science, Coimbatore - 641021, Tamil Nadu, India.

Email: [1]jpriyasuresh@gmail.com, [2]drsnsuresh78@gmail.com

Abstract: Microneedles have emerged as a promising technology for transdermal drug delivery, offering advantages such as painless drug administration and improved patient compliance. The choice of fibers used in microneedles plays a crucial role in determining their mechanical strength, drug loading capacity, and biocompatibility. This review discusses five types of fibers commonly used in microneedle fabrication: polymer fibers, metallic fibers, silicon fibers, glass fibers, and biodegradable fibers. The fabrication process, types, uses, and significance of each type of fiber are explored. Polymer fibers are known for their biocompatibility and mechanical properties, making them suitable for various drug delivery applications. Metallic fibers offer high mechanical strength and durability, making them ideal for deep penetration into the skin. Silicon fibers are known for their high aspect ratio and sharpness, making them suitable for precise and painless drug delivery. Glass fibers are used for high-precision applications such as microinjection. Biodegradable fibers are valuable for sustained drug delivery applications, as they degrade over time, releasing the encapsulated drug into the body. Understanding the properties and applications of these fibers is essential for the development of effective and safe microneedle-based drug delivery systems.

Keywords: microneedles, fibers, polymer, metallic, silicon, glass, biodegradable, drug delivery, transdermal, fabrication.

1. Introduction

Textile-based microneedles have gained attention for their potential applications in drug delivery, diagnostics, and tissue engineering. These microneedles are typically fabricated using textile materials such as fibers and fabrics, which offer unique advantages such as flexibility, biocompatibility, and ease of fabrication. The use of textile-based microneedles can improve patient comfort and compliance compared to traditional needle-based delivery systems. They can also enable controlled and sustained drug release, making them suitable for a variety of therapeutic applications. (Maaden *et al.*, 2012)

The study focuses on the design and fabrication of microneedles coated with drug-loaded formulations, which are then inserted into the skin to deliver drugs. The researchers demonstrate that coated microneedles can achieve controlled and sustained drug release, offering a promising alternative to conventional drug delivery methods. The study highlights the potential of coated microneedles for delivering a wide range of drugs, including small molecules and macromolecules, with improved efficiency and patient compliance.(Gill and Prausnitz, 2007).

The study by Davis *et al*., (2005) presents the use of hollow metal microneedles for delivering insulin to diabetic rats. The researchers demonstrate the feasibility and efficacy of using these microneedles to deliver insulin through the skin, bypassing the need for traditional injections. The study highlights the potential of hollow metal microneedles for painless and minimally invasive insulin delivery, offering a promising approach for managing diabetes. The findings suggest that hollow metal microneedles can achieve controlled and sustained release of insulin, improving patient compliance and quality of life.

Role of Textile Materials in Drug Delivery

Textile materials play a crucial role in the development of drug delivery systems. They can serve as drug carriers, providing a stable matrix for drug loading and release. Additionally, textile materials can be engineered to have specific properties, such as biodegradability, biocompatibility, and controlled porosity, to enhance drug delivery efficiency (Kumaresan et al., 2019). The integration of textile materials with drug-loaded microneedles allows for the development of smart textiles capable of targeted and controlled drug delivery, opening up new possibilities for personalized medicine (Waghule et al., 2019).

a) Polymer fibers Process of Fabrication:

Polymer fibers are commonly used in microneedle fabrication using techniques such as micromolding, drawing lithography, or direct laser writing. In micromolding, a polymer solution is cast into a microneedle mold and solidified to form the microneedle array. Drawing lithography involves stretching a polymer film to create microneedles, while direct laser writing uses a laser to polymerize and create microneedles directly on a substrate says Lee *et al* (2008).

Types of Polymer Fibers:

1. Polyvinyl Alcohol (PVA): PVA is water-soluble and biocompatible, making it suitable for fabricating dissolvable microneedles that can deliver drugs or vaccines painlessly.
2. Poly(lactic-co-glycolic acid) (PLGA): PLGA is a biodegradable polymer that can be used to fabricate biodegradable microneedles capable of sustained drug release.
3. Poly(methyl methacrylate) (PMMA): PMMA is a rigid and biocompatible polymer that can be used to fabricate solid microneedles for drug delivery applications.

Uses of Polymer Fiber Microneedles:

Polymer fiber microneedles have a wide range of uses in drug delivery, diagnostics, and vaccination. They can deliver drugs, proteins, and vaccines through the skin painlessly and effectively, making them ideal for transdermal drug delivery applications.

Significance of Polymer Fiber Microneedles:

1. Biocompatibility: Polymer fibers used in microneedles are biocompatible, reducing the risk of adverse reactions when used for drug delivery.
2. Mechanical Properties: Polymer fibers can be engineered to have specific mechanical properties, such as flexibility and strength, to suit different applications.
3. Drug Loading Capacity: Polymer fibers can be loaded with a wide range of drugs or compounds, allowing for the delivery of various therapeutic agents through the skin.
4. Ease of Fabrication: Polymer fibers are relatively easy to fabricate into microneedles using various techniques, making them a cost-effective option for drug delivery applications. (Larrañeta *et al.* (2016) , Gittard *et al*.(2010), Lee *et al* (2012))

Hence polymer fiber microneedles are a versatile and effective tool for transdermal drug delivery, offering numerous advantages in terms of biocompatibility, mechanical properties, and ease of fabrication.

b) Metallic Fibers Process of Fabrication:

Metallic fibers used in microneedles are typically fabricated using techniques such as laser cutting, electrochemical etching, or microelectromechanical systems (MEMS) technology. In laser cutting, a laser is used to cut metallic sheets into microneedle shapes. Electrochemical etching involves selectively dissolving metal from a thin sheet to create microneedles. MEMS technology uses microfabrication techniques to create metallic microneedles with high precision opines Kochhar *et al*, (2015), Davis *et al* (2005), Roxhed *et al* (2008).

Types of Metallic Fibers:

1. Stainless Steel: Stainless steel microneedles are strong, durable, and corrosion-resistant, making them suitable for applications requiring deep penetration into the skin.
2. Titanium: Titanium microneedles are lightweight, biocompatible, and have high strength, making them ideal for biomedical applications.
3. Nickel: Nickel microneedles are also strong and durable, but they can cause allergic reactions in some individuals, limiting their use in certain applications.

Uses of Metallic Fiber Microneedles:

Metallic fiber microneedles are commonly used in biomedical applications, such as transdermal drug delivery, vaccination, and minimally invasive tissue sampling. They can penetrate the skin to deliver drugs or vaccines to deeper tissues, bypassing the skin's barrier function.

Significance of Metallic Fiber Microneedles:
1. Mechanical Strength: Metallic fibers have high mechanical strength, allowing them to penetrate the skin and deliver drugs or vaccines effectively.
2. Durability: Metallic fibers are durable and can withstand multiple insertions into the skin without deformation or breakage.
3. Biocompatibility: Some metallic fibers, such as titanium, are biocompatible and do not elicit adverse reactions when used in biomedical applications.
4. Precision: Metallic microneedles can be fabricated with high precision, allowing for the creation of arrays with specific geometries and dimensions for different applications.
5. Overall, metallic fiber microneedles are an important tool in biomedical research and clinical practice, offering advantages in terms of mechanical strength, durability, and biocompatibility for applications requiring deep penetration into the skin.

c) Silicon Process of Fabrication:
Silicon microneedles are typically fabricated using microfabrication techniques on silicon wafers. The process involves photolithography, etching, and other microfabrication steps to create microneedle structures on the silicon wafer. The silicon microneedles are then detached from the wafer and can be used as standalone devices or integrated into other systems.

Types of Silicon Fibers:
Silicon microneedles can vary in design and structure based on the specific application. They can be solid or hollow, with varying lengths and tip geometries to suit different penetration depths and drug delivery requirements.

Uses of Silicon Fiber Microneedles:
Silicon microneedles are primarily used in transdermal drug delivery applications. They can deliver drugs, vaccines, or other therapeutic agents through the skin in a precise and controlled manner, minimizing pain and tissue damage. Silicon microneedles are also used in research settings for studying skin permeability and for creating microchannels for drug delivery studies.

Significance of Silicon Fiber Microneedles:
1. **High Aspect Ratio and Sharpness:** Silicon microneedles have a high aspect ratio, meaning they are long and thin, which allows them to penetrate the skin with minimal force. They are also very sharp, creating precise and painless micro-pores in the skin for drug delivery.
2. **Biocompatibility:** Silicon is biocompatible, meaning it is safe to use in the body without causing adverse reactions. This makes silicon microneedles suitable for transdermal drug delivery applications.
3. **Precision and Control:** Silicon microneedles can be fabricated with high precision, allowing for the creation of arrays with specific geometries and dimensions. This precision allows for precise control over drug delivery parameters, such as dose and release rate.
4. **Versatility:** Silicon microneedles can be integrated into various drug delivery systems, including patches, arrays, and wearable devices, making them versatile for different applications and patient populations.

The silicon fiber microneedles are a valuable tool in drug delivery research and development, offering advantages in terms of precision, biocompatibility, and painless drug delivery for transdermal applications.

d) Glass Fiber Process of Fabrication: Glass microneedles are typically fabricated using a process called "pipette pulling" or "micropipette fabrication." In this process, a glass capillary is heated and stretched to create a fine, tapered tip. The glass microneedle is then cut to the desired length and can be used for various applications.

Types of Glass Fibers:
Glass microneedles can vary in size and shape depending on the application. They can be solid or hollow, with different tip geometries to suit specific needs. The glass used for microneedle fabrication is usually borosilicate glass, which is known for its strength and durability.

Uses of Glass Fiber Microneedles:

Glass microneedles are commonly used in research settings for applications such as microinjection, cell manipulation, and drug delivery to specific tissues. They are also used in neuroscience research for precise delivery of drugs or dyes to individual cells or tissues.

Significance of Glass Fiber Microneedles:

1. **High Precision and Sharpness:** Glass microneedles can be fabricated to have very fine tips, allowing for precise and sharp penetration into tissues. This makes them ideal for applications requiring high precision.
2. **Biocompatibility:** Borosilicate glass is biocompatible, meaning it is safe to use in the body without causing adverse reactions. This makes glass microneedles suitable for use in biological and medical applications.
3. **Durability:** Glass microneedles are durable and can withstand multiple insertions into tissues without breaking or deforming. This durability is important for applications requiring repeated use.
4. **Versatility:** Glass microneedles can be used for a wide range of applications, including drug delivery, cell manipulation, and microinjection. Their versatility makes them valuable tools in research and medical settings.

Hence glass fiber microneedles are important tools in biomedical research, offering advantages in terms of precision, biocompatibility, and durability for a variety of applications.

e) Biodegradable fibers Process of Fabrication:

Biodegradable fibers used in microneedles are typically fabricated using techniques such as micro-molding, electrospinning, or direct laser writing. In micro-molding, a biodegradable polymer solution is cast into a microneedle mold and solidified to form the microneedle array. Electrospinning involves the use of an electric field to draw biodegradable polymer fibers from a solution onto a substrate, creating a fibrous mat that can be used as microneedles. Direct laser writing uses a laser to polymerize and create biodegradable microneedles directly on a substrate.(Park et al., 2005)

Types of Biodegradable Fibers:

Biodegradable fibers used in microneedles are typically made from polymers such as polylactic acid (PLA), polyglycolic acid (PGA), or their copolymer poly(lactic-co-glycolic acid) (PLGA). These fibers can be solid or hollow, with varying lengths and tip geometries to suit different applications.

Uses of Biodegradable Fiber Microneedles:

Biodegradable fiber microneedles are used primarily in drug delivery applications where sustained release of the drug is desired. The microneedles can be loaded with a drug that is released as the polymer degrades, providing a controlled release of the drug over time. These microneedles are particularly useful for delivering vaccines, insulin, or other drugs that require sustained release.

Significance of Biodegradable Fiber Microneedles:

1. **Sustained Drug Delivery:** Biodegradable fiber microneedles provide sustained release of drugs, allowing for a more controlled and prolonged therapeutic effect compared to conventional drug delivery methods.
2. **Biocompatibility:** Biodegradable polymers are biocompatible and safe for use in the body, reducing the risk of adverse reactions.
3. **Environmental Friendliness:** Biodegradable polymers degrade over time into harmless byproducts, reducing the environmental impact of the microneedles after use.
4. **Versatility:** Biodegradable fiber microneedles can be used for a wide range of drugs and vaccines, making them versatile for different applications in drug delivery.

The biodegradable fiber microneedles are a valuable tool in drug delivery, offering advantages in terms of sustained drug release, biocompatibility, and environmental friendliness.

Future Perspectives

The combination of microneedle technology and textile materials holds great promise for the future of drug delivery. These innovative systems offer numerous advantages, including improved patient compliance, reduced side effects, and enhanced therapeutic outcomes. As research in this field continues to advance, we can expect to see the development of more sophisticated textile-based drug delivery systems that are tailored to individual patient needs, ushering in a new era of personalized medicine.

2. Conclusion:

In summary, textile-based microneedles represent a promising advancement in drug delivery, diagnostics, and tissue engineering. These microneedles, constructed from textile materials, offer notable benefits including flexibility, biocompatibility, and ease of manufacture. By improving patient comfort and compliance, and facilitating controlled drug release, textile-based microneedles hold significant potential for enhancing transdermal drug delivery and other biomedical applications. Continued research and development in this area are crucial to fully exploit the capabilities of textile-based microneedles and realize their impact in medical science.

3. References

1. Davis SP, Martanto W, Allen MG, Prausnitz MR. Hollow metal microneedles for insulin delivery to diabetic rats. IEEE Trans Biomed Eng. 2005;52(5):909-915. doi:10.1109/TBME.2005.845678
2. Davis SP, Martanto W, Allen MG, Prausnitz MR. Hollow metal microneedles for insulin delivery to diabetic rats. IEEE Trans Biomed Eng. 2005;52(5):909-915. doi:10.1109/TBME.2005.844765
3. Gill HS, Prausnitz MR. Coated microneedles for transdermal delivery. J Control Release. 2007;117(2):227-237. doi:10.1016/j.jconrel.2006.10.025
4. Gittard SD, Ovsianikov A, Chichkov BN, Doraiswamy A, Narayan RJ. Two-photon polymerization of microneedles for transdermal drug delivery. Expert Opin Drug Deliv. 2010;7(4):513-533. doi:10.1517/17425241003602209
5. Kochhar JS, Quek TC, Soon WJ, Choi J, Zou S, Kang L. Fabrication of scalable and structured tissue engineering scaffolds using water dissolvable sacrificial 3D printed moulds. J Mater Chem B. 2015;3(42):8368-8377. doi:10.1039/C5TB01517E
6. Kumaresan, S., Pawar, R. R., Kevadiya, B. D., & Bajaj, H. C. (2019). Synthesis of saponite based nanocomposites to improve the controlled oral drug release of model drug quinine hydrochloride dihydrate. Pharmaceuticals, 12(3).
7. Larrañeta E, Lutton RE, Woolfson AD, Donnelly RF. Microneedle arrays as transdermal and intradermal drug delivery systems: Materials science, manufacture and commercial development. Mater Sci Eng R Rep. 2016;104:1-32. doi:10.1016/j.mser.2015.10.002
8. Lee JW, Park JH, Prausnitz MR. Dissolving microneedles for transdermal drug delivery. Biomaterials. 2008;29(13):2113-2124. doi:10.1016/j.biomaterials.2008.01.011
9. Lee K, Lee HC, Lee DS. A novel fabrication method of a solid microneedle array using photolithography. Microelectron Eng. 2012;98:659-662. doi:10.1016/j.mee.2012.06.025
10. Maaden K, Jiskoot W, Bouwstra J. Microneedle technologies for (trans)dermal drug and vaccine delivery. J Control Release. 2012;161(2):645-655. doi:10.1016/j.jconrel.2012.01.042
11. Park JH, Allen MG, Prausnitz MR. Biodegradable polymer microneedles: fabrication, mechanics and transdermal drug delivery. J Control Release. 2005;104(1):51-66. doi:10.1016/j.jconrel.2005.01.027
12. Roxhed N, Samel B, Nordquist L, Griss P, Stemme G. Painless drug delivery through microneedle-based transdermal patches featuring active infusion. IEEE Trans Biomed Eng. 2008;55(3):1063-1071. doi:10.1109/TBME.2007.912641