International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Microneedle Technology: Innovations and Applications in Modern Healthcare

Kolpe Punam Sudhakar*[1], *Burande Meet Ganesh*[2], *Barde Shweta Chhagan*[3], *Mr. Waghmare Rahul Sugriv*[4], *Dr. Satpute Kranti Limbajirao*[5]

Dayanand College of Pharmacy, Latur

ABSTRACT

Skin- based medicine delivery has several benefits over oral or parenteral routes, including avoiding hepatic first- pass metabolism, maintaining a constant plasma concentration, and being safe. The main obstacle to transdermal distribution, still, is that only a small number of strong specifics with optimal physicochemical characteristics can interact with cells and passively diffuse through skin walls to reach therapeutic levels. Specifics are administered through the skin using transdermal devices. Its larger operation is, still, confined by factors including the molecules' hydrophilicity and molecular weight. Better medication distribution is made possible by the design of microneedles. The four basic morphological orders of microneedles are solid, coated, dissolving, and hollow. The fabrication process is told by the type of material utilised. There's discussion of a variety of fabrication accoutrements, both biodegradable and non-biodegradable. silicone, ceramics, Metals, synthetic materials, and biodegradable polymers like carbohydrates can all be used to produce microneedles. Every substance has benefits and drawbacks of its own.. While silicones are easy to produce but brittle, stainless steel has good biocompatibility but is largely sharp. Given the variety of forms and materials available, the ease of product and the eventuality for coming- generation therapies, microneedle technology has enormous potential.

Key words: plasma concentration, hepatic first- pass metabolism, transdermal medicine administration, fashion of microneedles, skin barriers, Permeability of medicines, materials that are biodegradable andnon-biodegradable, biocompatibility.

In recent years, microneedles have gained more attention in biomedical fields such fluid extraction, drug delivery, and biosensing .Medications has been administered in a number of methods to prolong human life and enhance health. From chewing medicinal leaves to using pills, capsules, injectables, and implantable devices, drug delivery techniques have undergone significant advancements.Microneedle structures that can comfortably pierce the stratum corneum (SC), the skin's outermost layer.The top layer of the dermis, which is above the blood vessels, can be reached by the points of the microneedles penetrating the epidermal layer of skin. In order to further prevent bleeding and suffering, the microneedles would not come into contact with the nerve ends.The microneedles can provide the devices, such the electrodes, to obtain the biomedical signals, or they can create microchannels on the skin where molecules can flow.In biomedical applications, microneedles' amazing function stems from their 3D structure, which allows them to penetrate the skin barrier with minimal invasiveness, allowing self-administration patient-friendly.Using microneedles to give drugs offers several benefits, including eliminating the effects of gastrointestinal digestion, increasing medication absorption, extending the duration of action, and allowing patients to self-administer without the assistance of a physician.The microneedle method makes it possible to continuously monitor the biomarkers in interstitial fluid for biosensing.the drawbacks of the two conventional dose forms is microneedle medication delivery. The method has been tested to transport cosmeceuticals, micro/nanoparticles, and a variety of macromolecules in addition to small molecules. Both coated and dissolving microneedles have recently been tested for use in diagnostic, patient monitoring, and noninvasive transdermal immunization applications.

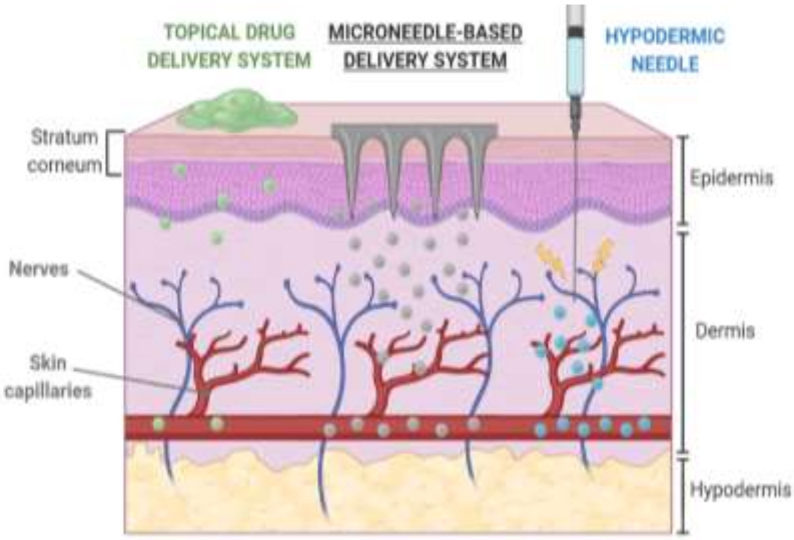

Figure.1 Microneedle Based Deliver

There are four different varieties of microneedles: coated, solid, dissolving, and hollow. Additionally, a variety of materials, including metal, inorganic, and polymer materials, can be used to make microneedles. In several scientific domains, microneedles of various kinds and compositions serve distinct purposes. The microneedle delivery system has been widely employed in recent years to administer vaccinations, medications, genes, proteins, and RNA. Microneedles and other nano-carriers have also been used in immunotherapy, diabetes treatment, cancer therapy, and diagnosis with positive results.

Need of microneedle:-

- Provides controlled drug delivery at a specific rate.
- To deliver drug quickly with minimal discomfort.
- Delivered deep into the body.
- Prevents penetration without bending, breaking or delaminating.
- Biocompatible.

Advantages:-

The benefits of microneedle as drug delivery are Avoiding first pass metabolism, preventing pain and bleeding, enabling self-administration, improving patient compliance because of the lack of needle phobia, increasing the stability of the encapsulated drug molecule, and delivering the drug immediately and precisely are all advantages of using microneedles for drug delivery. Facilitate rapid skin absorption, shield the medication from the adverse gastrointestinal tract environment, and improve compatibility.

Disadvantages:-

The drawbacks of microneedle as drug delivery are longer wear time, multiple patches in the environment, special energy requirements and good biocompatible materials, Skin irritation, redness, pain, inflammation, infection, at the application site. External factors such as skin hydration can affect the effectiveness of microneedling and alter the absorption of medication and the thickness of the stratum corneum and other layers of the skin vary from person to person, which can lead to inconsistent drug penetration and drug distribution.

Material used for microneedles preparation

The materials used to make microneedles may be broadly classified into three categories: metal, inorganic, and polymer. Different types of microneedles may be made using these materials in a variety of ways.

1. Metal Materials:-

Transdermal medication delivery devices frequently employ metal materials because of their mechanical strength and durability. It is possible to create solid, coated, and hollow microneedles using metal materials. The good mechanical and physical qualities, cheap cost, high biocompatibility, and difficulty of breaking are some of the benefits of using metal materials as the structural materials for microneedles.

2. Inorganic material:-

The most widely used inorganic materials for creating microneedles are ceramics, glass, and silicon. Since the features and attributes of the microneedles made from inorganic materials are comparable to those of metal materials, inorganic materials may also be used to create solid, coated, and hollow microneedles.However, the primary issues influencing the use of inorganic microneedles are biocompatibility and brittle silicon.

3. Polymer materials:-

For the production of microneedles, polymer materials are seen to be the most promising when compared to metal and inorganic materials.Polymers are favored because of their low cost, hygienic use, biocompatibility, biodegradability, swelling, and dissolving properties.The production of hydrogel-forming and dissolving microneedle arrays mostly uses polymers.Since silicon is brittle and does not break down in the body, alternative materials, such polymers, were used for making microneedles.They may be used to make hollow, dissolving, coated, and solid microneedles.

Microneedle Types:-

Microneedles can be widely categorized based on their manufacturing material or delivery characteristics. There are several types of microneedles, including coated, solid, hollow, and dissolving.

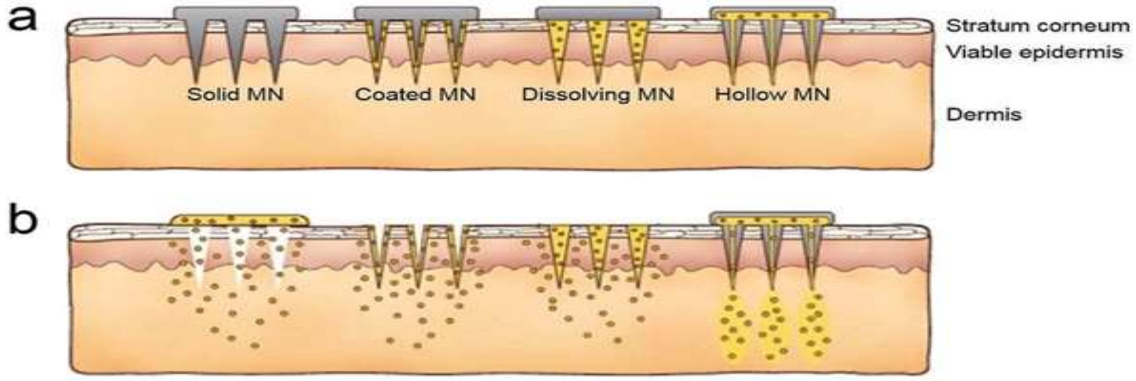

Figure.2 Types of microneedles

1. Coated:-

A coated microneedle consists of a sharp, solid needle core that has a thin layer of a solid film on it. A solid needle with a medicinal solution applied to its surface is called a coated microneedle. It usually contains less of the medication; this depends on the thickness of the coated layer.This film includes the active drug and other inactive ingredients that dissolve in water. The effectiveness of delivering a drug with a coated microneedle (MN) relies on accurately applying a consistent drug layer onto the microneedles. Coated microneedles can deliver proteins and DNA in a way that is less invasive than traditional methods.The quick delivery of medication to the skin is a benefit of a coated MN; yet, the remaining medication at the needle's tip may infect further patients. Finally, its results of the coated MN vaccine administration were comparable with those of intradermal and intramuscular vaccinations.

2. Solid:-

Solid microneedles can be used to make tiny punctures in the skin that facilitate the easy delivery of molecules and therapeutic substances. This type of microneedle structure is designed to penetrate the outermost layer of the skin (the stratum corneum) to improve drug delivery to the deeper layers (the dermis). This enhances

The body's ability to absorb the drug and speeds up its transport through the skin. Solid microneedles can be utilized as a pretreatment for the skin since they create micron-sized

Holes on the skin's surface when they are introduced and withdrawn. By applying a drug patch, the drug can directly penetrate the skin layers through the micron-sized channels created by the needles' sharp points, enhancing the rate of penetration.Solid microneedles are easier to make and have superior mechanical qualities than hollow ones.Furthermore, an array of materials, including silicon, metals, and polymers, may be used to produce the solid microneedle.

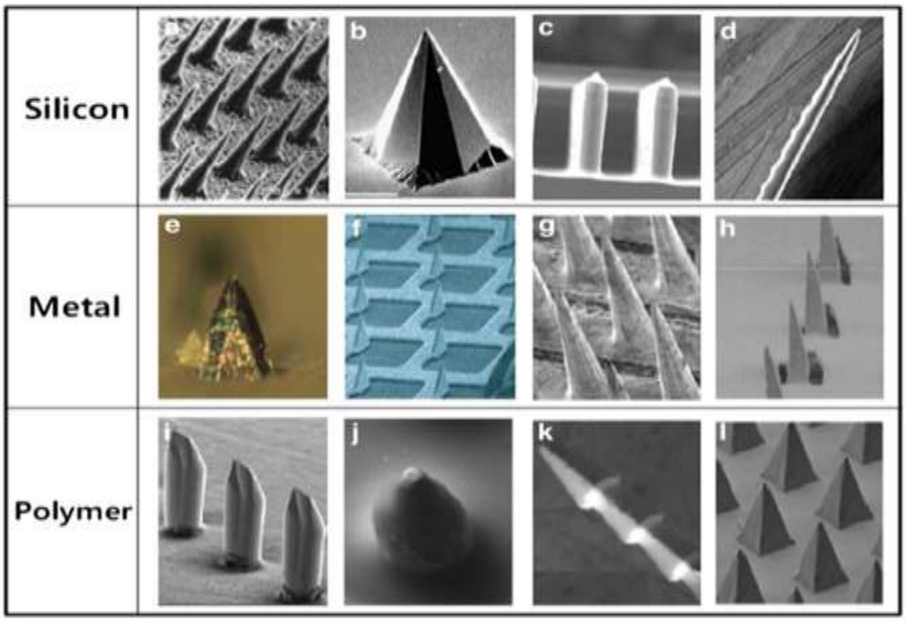

Figure 3solid microneedles. Silicon microneedles (a to d), metal microneedles(e to h), polymer microneedles(i to l)

3. Hollow

A hollow microneedle has a design featuring an empty core or chamber where the drug fluid is injected or stored. Compared to solid microneedles, hollow microneedles can manage a larger amount of drug solution.A liquid formulation flowing under pressure is used to administer the drug. With this method, significant dosages may be injected into the dermal layer. Because of their fragility and structure, hollow MNs are challenging to produce.The design of hollow microneedles may be altered to modify the pressure, flow, and rate of medication release. It is possible to regulate the microneedle aspect ratio to provide a time-varying delivery rate, an even infusion, or fast release. The drawbacks of hollow micro -needles include blockage and leaking during injection. In terms of the design of the needle and the techniques used for insertion, they too need special consideration because they are comparatively weaker. In a study conducted on diabetic rats, microneedles were examined for their ability to deliver insulin. The research found that hollow microneedles provide pharmacodynamic profiles similar to those achieved with traditional hypodermic injections.

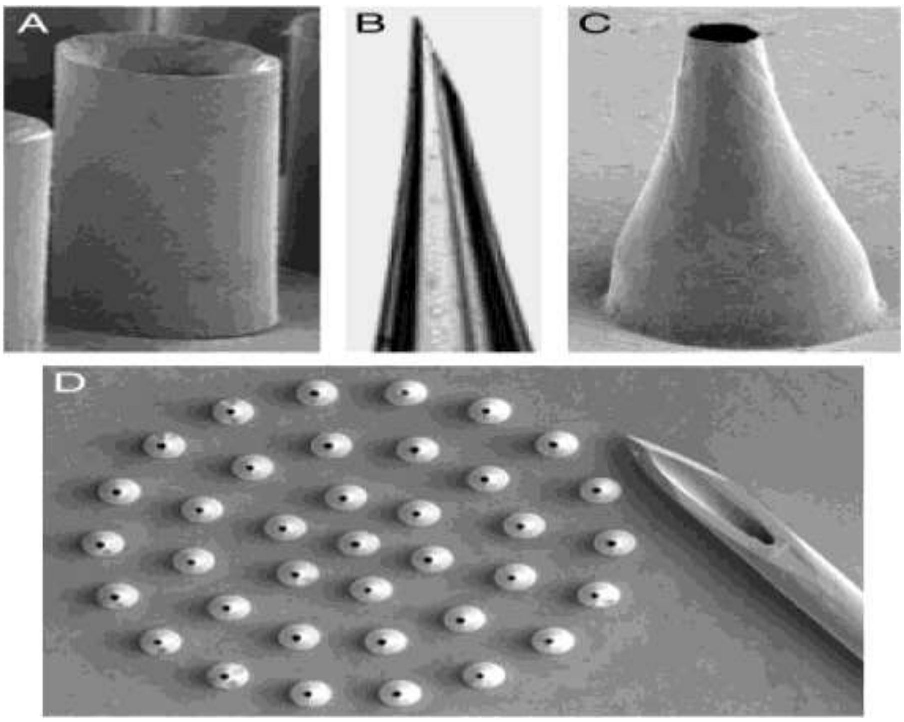

Figure: 4 Hollow microneedles. A-Straight-walled metal microneedle B-Tip of a tapered, beveled, glass microneedle, C-Tapered, metal microneedle, D-Array of tapered metal microneedles.

4. Dissolving

Dissolving microneedles operate by a 'poke and release' principle. Biodegradable polymers are used to produce dissolving microneedles**.**Dissolving microneedles provide a number of benefits over solid or coated microneedles, including ease of manufacture, convenience, and high drug loading.A two-step casting procedure may be used to load the dissolvable MN tip quickly. When the dissolvable MN is inserted into the skin, the drug load is released and diffused by the needle tip dissolving. The best substance to use in the production of the dissolvable MN is water-soluble.Furthermore; one of the best methods for creating Microneedle Technology: Innovations and Applications in Modern Healthcare

The microneedle mold is filled with a concentrated polymer solution, dried, or filled with melted polymer and allowed to harden as part of the micro-molding process. The possibility of a delay in disintegration and the impracticability of full insertion are two of the main drawbacks of employing dissolvable microneedles.

Mechanism of drug delivery:

The diffusion method is used to administer the medication topically. The skin is temporarily disturbed in the microneedle medication delivery device.In order to administer enough medication to provide the necessary therapeutic response; hundreds of microneedles are arranged in arrays on a small patch, similar to a conventional transdermal patch that is available in stores. It avoids the barrier layer by penetrating the stratum corneum. When the medication reaches the site of action, it immediately enters the epidermis or higher dermis layer, enters the systemic circulation, and exhibits a therapeutic reaction.

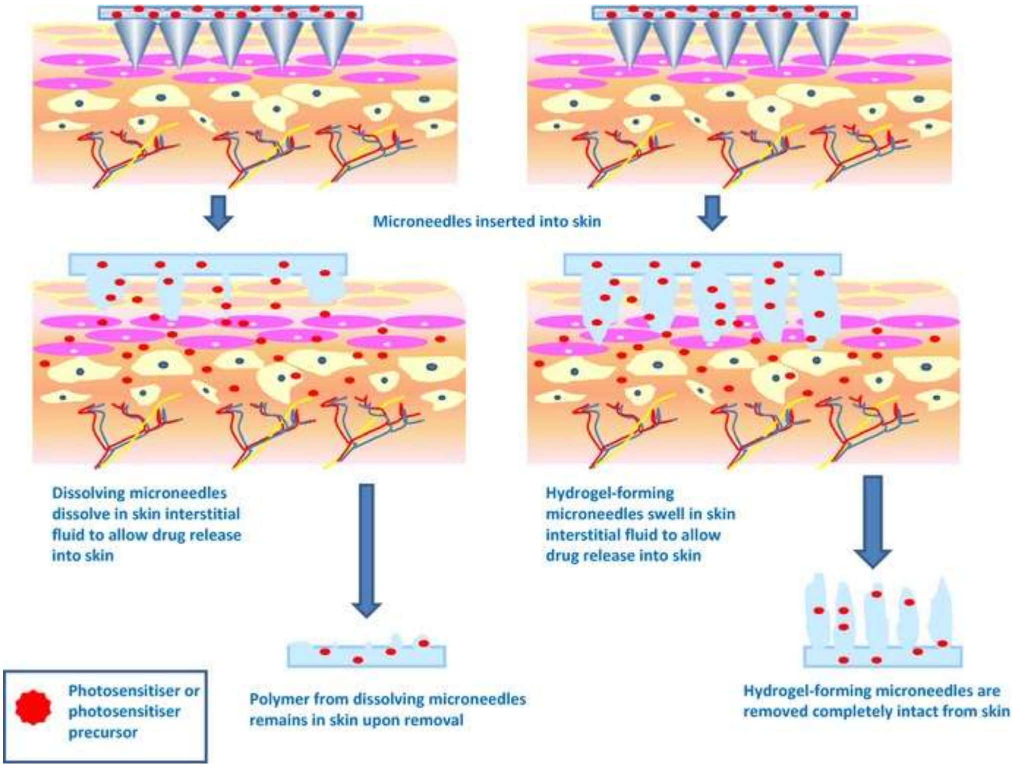

Figure: 5 Mechanism of drug delivery

Application of microneedles:-

After injection and oral administration, transdermal drug delivery systems have become the third most used drug delivery route in recent years. The delivery mechanism for microneedles in particular has shown a lot of promise. It is safe, easy to use, painless, and increases patient compliance in addition to increasing the effectiveness of drug delivery. These days, this approach is widely employed in many other disciplines, such as diabetes treatment, cancer therapy, diagnosis, and pain and inflammation management.

1. **Drug delivery**

By avoiding the first-pass metabolism and increasing bioavailability, microneedles can be utilized to transdermally administer medications, vaccinations, and other therapeutic substances.

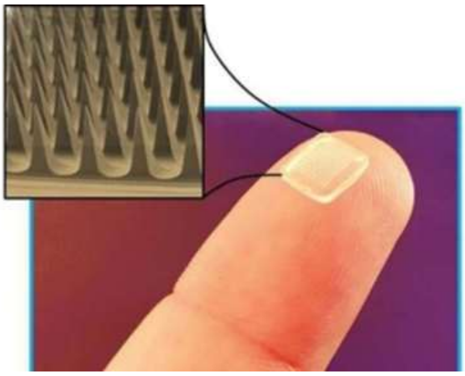

Figure: 6 Microneedle drug delivery

When compared to conventional injections, microneedles are typically painless or cause very little discomfort. Since microneedles are simple to self-administer at home, patient compliance is increased. Numerous medications can be administered with microneedles, such as:

Vaccinations: It has been demonstrated that microneedles work well for administering vaccinations against hepatitis B, influenza, and other illnesses.

Hormones: Growth hormone and insulin can be administered by microneedles.

Painkillers: Bupivacaine and lidocaine are two examples of painkillers that may be administered by microneedles.

Cancer medications: Chemotherapy and immunotherapy treatments can be administered using microneedles.

2. **Cosmetics:-**

Microneedles can deliver cosmetic ingredients into the skin by creating tiny channels, without touching the nerves. 3D printing has been used to create skin care products applied to the surface of the skin. Cosmetic compounds including peptides, growth factors, and antioxidants can be delivered into the skin using microneedles, which will have anti-aging and skin-rejuvenating benefits.

Figure: 7 Microneedle used in cosmetics

The improved distribution of acetyl-hexapeptide 3 (AHP-3) for the treatment of wrinkles in the skin can be achieved using customized 3D-printed microneedle patches made with the digital light processing (DLP) technique.

3. **Diagnostics**

MNs painless biofluid withdrawal procedure helps patients overcome the discomfort and anxiety associated with traditional blood withdrawal techniques. Additionally, centrifugation is used to collect the interstitial fluid from MNs in order to identify biomarkers. For diagnostic reasons, interstitial fluid or blood samples can be collected with microneedles.MNs minimally invasive nature and user-friendliness make them an exceptional instrument for identifying a broad range of biomarkers from skin interstitial fluid, including small molecule metabolites, nucleic acids, proteins, and human cells.MN-based sensors that have a pH-sensitive iridium oxide layer applied to their surface aid in the detection of in vivo concentrations of β-lactam antibiotics. The sensor measures a change in local pH caused by the lactamase enzyme hydrolyzing the lactam ring on the electrode surface. These biosensors are stable and sterile for up to two weeks at 20 °C.They also demonstrated the effectiveness of flexible MNs in extracting ISF invitro by compression for continuousglucosemonitoring andinvivo (mouse).

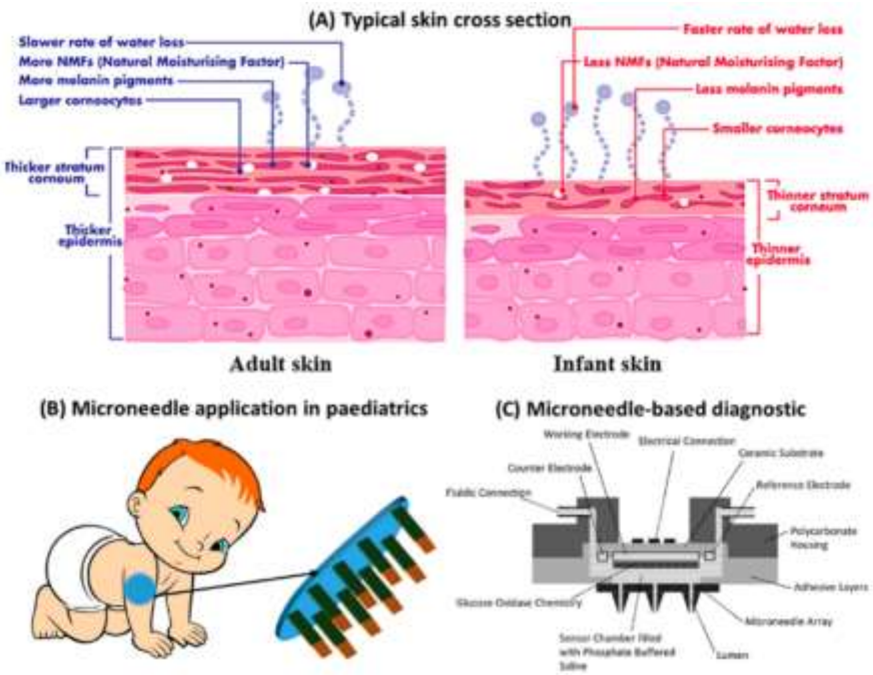

Figure:8 Microneedle used as Diagnostic Purpose

4. Biosensing

The identification of biomarkers for certain illnesses may be done continuously and painlessly withmicroneedle sensing.Microneedles have been investigated for the development of various biosensors, such as those for glucose, lactate, alcohol, and beta-lactam.Target molecules and biomarkers are readily observable utilizing the samples that the microneedle arrays gather, making three-dimensionally printed microneedles suitable for point of care biosensing applications.

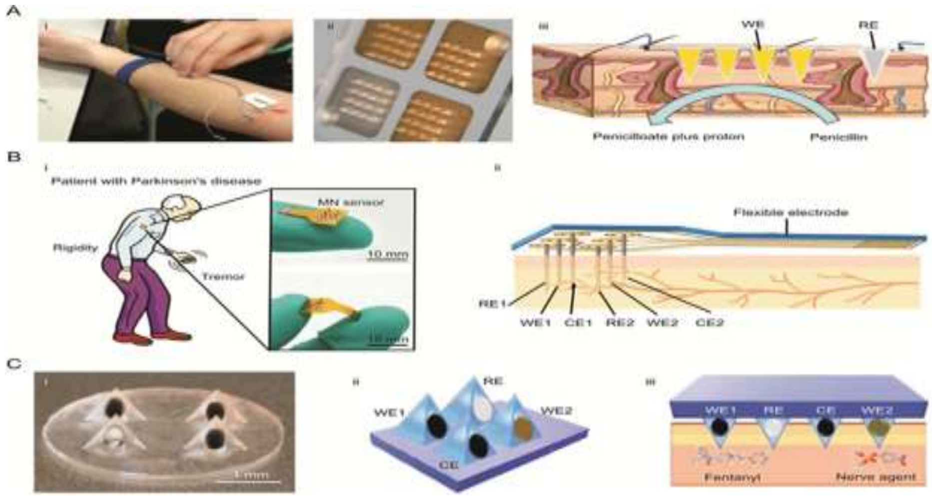

Figure: 9 Microneedle used in biosensing

5. Disease Treatment

Therapeutics and bioactive substances have been delivered by three-dimensionally printed microneedles to treat a variety of illnesses. Polymeric microneedles were created using the stereolithography technology, and insulin was applied to them using an ink-jet process. Trehalose, mannitol, and xylitol, the drug carriers, maintained the stability and integrity of the insulin.

6. Wound Healing

Researchers made 3D-printed microneedles from a unique acrylate material with anti-microbial qualities by using visible light and sophisticated printing processes. The potential of these microneedles to cure wounds and eradicate skin infections has been quite promising.3D printing and other mold - free manufacturing processes have been thoroughly researched for their technical support in creating complex designs with high drug-loading capacities and better integrated medical microneedles for wound healing applications.

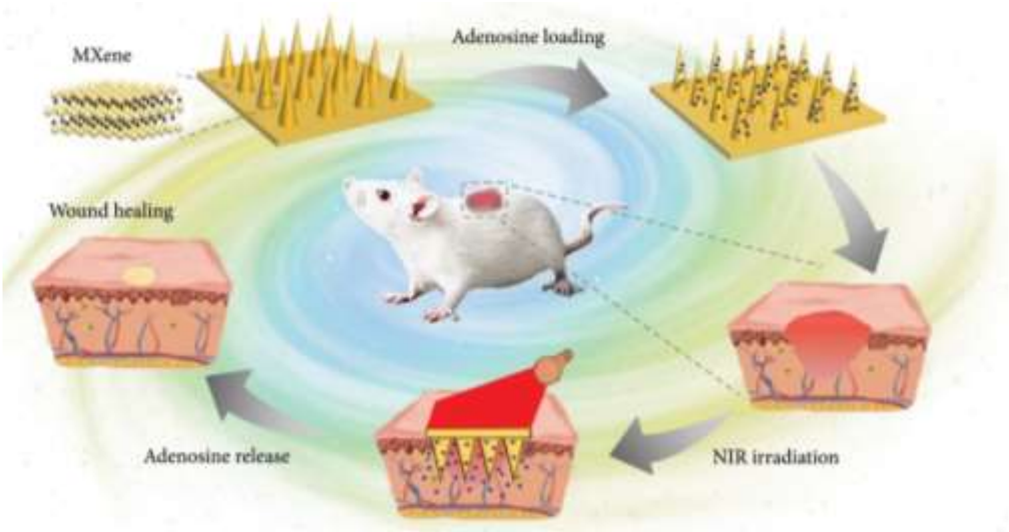

Figure: 10Microneedle used in wound healing

7. Vaccine Delivery

A new vaccine delivery technique, microneedles provide a number of benefits over conventional hypodermic needles. They are tiny projections that may easily pierce the skin and carry vaccinations to the dermis, which is rich in immune cells. This approach can even be self-administered, is less invasive, and may be more effective. MNs are capable of delivering vaccinations and high molecular weight proteins (up to 200 Da) via the skin. By communicating with T cells, which are then attached to the major histocompatibility complex (MHC complex) to induce CD4+ and CD8+ cytotoxic cells, dendritic cells with antigenic fragments found in the epidermis' outermost layer trigger the immune response. If an antigen enters the body, Langerhans cells can also trigger the immune response by triggering the production of antibodies by the lymphocytes. In order to administer therapeutic medications, such as vaccines, to these layers of the skin, MN technologies are facilitated by the penetration of the stratum corneum layer and the deposition of the NP formulation into these layers of skin that are rich in immune cells.

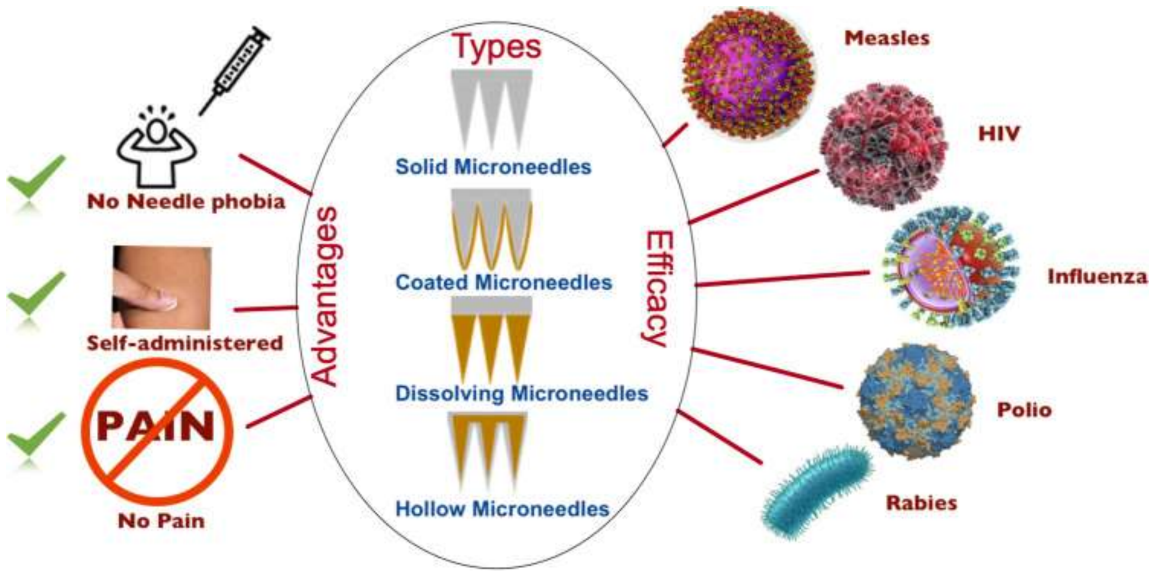

Figure: 11 Microneedle used in vaccine delivery

References

1. Maia, R.F., Machado, P., Rodrigues, R.O. *et al.* Recent advances and perspectives of MicroNeedles for biomedical applications. *Biophys Rev* (2025). https://doi.org/10.1007/s12551-025-01317-7

2. Luo, X., Yang, L. & Cui, Y. Microneedles: materials, fabrication, and biomedical applications. *Biomed Microdevices* **25**, 20 (2023). https://doi.org/10.1007/s10544-023-00658-y

3. Aldawood, F.K.; Andar, A.; Desai, S. A Comprehensive Review of Microneedles: Types, Materials, Processes, Characterizations and Applications. *Polymers* **2021**, *13*, 2815. https://doi.org/10.3390/polym13162815

4. Aldawood, F.K.; Andar, A.; Desai, S. A Comprehensive Review of Microneedles: Types, Materials, Processes, Characterizations and Applications. Polymers 2021, 13, 2815. https://doi.org/10.3390/ polym13162815

5. Ranjan, A., & Shukla, P. (2022). *A Comprehensive Review on Microneedles INTRODUCTION* (Vol. 25, Issue 3). www.ijppr.humanjournals.com

6. Donnelly, R. F., &Prausnitz, M. R. (2024). The promise of microneedle technologies for drug delivery. *Drug Delivery and Translational Research*, *14*(3). https://doi.org/10.1007/s13346-023-01430-8

7. Hamdan, I. (2024). Microneedle and drug delivery across the skin: An overview. *Pharmacia*, *71*. https://doi.org/10.3897/pharmacia.71.e112503

8. Ahmed Saeed AL-Japairai, K., Mahmood, S., HamedAlmurisi, S., Reddy Venugopal, J., RebhiHilles, A., Azmana, M., & Raman, S. (2020). Current trends in polymer microneedle for transdermal drug delivery. In *International Journal of Pharmaceutics* (Vol. 587). Elsevier B.V. https://doi.org/10.1016/j.ijpharm.2020.119673

9. Ma, G., & Wu, C. (2017). *Microneedle, bio-microneedle and bio-inspired microneedle: a review*.

10. Nagarkar, R., Singh, M., Nguyen, H. X., &Jonnalagadda, S. (2020). A review of recent advances in microneedle technology for transdermal drug delivery. In *Journal of Drug Delivery Science and Technology* (Vol. 59). Editions de Sante. https://doi.org/10.1016/j.jddst.2020.101923

11. Aldawood, F. K., Andar, A., & Desai, S. (2021). A comprehensive review of microneedles: Types, materials, processes, characterizations and applications. In *Polymers* (Vol. 13, Issue 16). MDPI AG. https://doi.org/10.3390/polym13162815

12. Kim, Y. C., Park, J. H., &Prausnitz, M. R. (2012). Microneedles for drug and vaccine delivery. In *Advanced Drug Delivery Reviews* (Vol. 64, Issue 14, pp. 1547–1568). https://doi.org/10.1016/j.addr.2012.04.005

13. Cheung, K., & Das, D. B. (2016). Microneedles for drug delivery: trends and progress. In *Drug Delivery* (Vol. 23, Issue 7, pp. 2338–2354). Taylor and Francis Ltd. https://doi.org/10.3109/10717544.2014.986309

14. Amarnani, R., &Shende, P. (2022). Microneedles in diagnostic, treatment and theranostics: An advancement in minimally-invasive delivery system. *Biomedical Microdevices*, *24*(1). https://doi.org/10.1007/s10544-021-00604-w

15. Luo, X., Yang, L., & Cui, Y. (2023). Microneedles: materials, fabrication, and biomedical applications. In *Biomedical Microdevices* (Vol. 25, Issue 3). Springer. https://doi.org/10.1007/s10544-023-00658-y

16. Aldawood, F. K., Andar, A., & Desai, S. (2021). A comprehensive review of microneedles: Types, materials, processes, characterizations and applications. In *Polymers* (Vol. 13, Issue 16). MDPI AG. https://doi.org/10.3390/polym13162815

17. Tucak, A., Sirbubalo, M., Hindija, L., Rahić, O., Hadžiabdić, J., Muhamedagić, K., Čekić, A., &Vranić, E. (2020). Microneedles: Characteristics, materials, production methods and commercial development. In *Micromachines* (Vol. 11, Issue 11). MDPI AG. https://doi.org/10.3390/mi11110961

18. Waghule, T., Singhvi, G., Dubey, S. K., Pandey, M. M., Gupta, G., Singh, M., &Dua, K. (2019). Microneedles: A smart approach and increasing potential for transdermal drug delivery system. In *Biomedicine and Pharmacotherapy* (Vol. 109). https://doi.org/10.1016/j.biopha.2018.10.078

19. Waghule, T., Singhvi, G., Dubey, S. K., Pandey, M. M., Gupta, G., Singh, M., &Dua, K. (2019). Microneedles: A smart approach and increasing potential for transdermal drug delivery system. In *Biomedicine and Pharmacotherapy* (Vol. 109). https://doi.org/10.1016/j.biopha.2018.10.078

20. Halder, J., Gupta, S., Kumari, R., Gupta, G. das, & Rai, V. K. (2021). Microneedle Array: Applications, Recent Advances, and Clinical Pertinence in Transdermal Drug Delivery. In *Journal of Pharmaceutical Innovation* (Vol. 16, Issue 3). https://doi.org/10.1007/s12247-020-09460-2

21. Rad, Z. F., Prewett, P. D., & Davies, G. J. (2021). An overview of microneedle applications, materials, and fabrication methods. *Beilstein Journal of Nanotechnology*, *12*. https://doi.org/10.3762/BJNANO.12.77

22. Noh, I., Lee, K., & Rhee, Y. S. (2022). Microneedle systems for delivering nucleic acid drugs. In *Journal of Pharmaceutical Investigation* (Vol. 52, Issue 3). https://doi.org/10.1007/s40005-021-00558-4

23. An, H., Gu, Z., Huang, Z., Huo, T., Xu, Y., Dong, Y., & Wen, Y. (2024). Novel microneedle platforms for the treatment of wounds by drug delivery: A review. In *Colloids and Surfaces B: Biointerfaces* (Vol. 233). https://doi.org/10.1016/j.colsurfb.2023.113636

24. Mansoor, I., Eassa, H. A., Mohammed, K. H. A., Abd El-Fattah, M. A., Abdo, M. H., Rashad, E., Eassa, H. A., Saleh, A., Amin, O. M., Nounou, M. I., &Ghoneim, O. (2022). Microneedle-Based Vaccine Delivery: Review of an Emerging Technology. In *AAPS PharmSciTech* (Vol. 23, Issue 4). https://doi.org/10.1208/s12249-022-02250-8

25. Ingrole, R. S. J., & Gill, H. S. (2019). Microneedle coating methods: A review with a perspective. In *Journal of Pharmacology and Experimental Therapeutics* (Vol. 370, Issue 3). https://doi.org/10.1124/jpet.119.258707