**International Journal of Pharmacy and Pharmaceutical Research (IJPPR)**
Volume 31, Issue 4, April 2025 **ijppr.humanjournals.com** ISSN: 2349-7203

# Microneedle Technology for Transdermal Drug Delivery

**Saumya Singh[1], Sanskar Gupta[2], Sagar Singh[3*], Vibha Shukla[4], Ankit Shukla[5]**

[1]B. Pharm. Scholar, Department of Pharmacy, Axis Institute of Pharmacy, Kanpur, India.
[2]B. Pharm. Scholar, Department of Pharmacy, Axis Institute of Pharmacy, Kanpur, India.
[3*]Assistant Professor, Department of Pharmacology, Axis Institute of Pharmacy, Kanpur, India.
[4]Assistant Professor, Department of Pharmacology, Axis Institute of Pharmacy, Kanpur, India.
[5]Associate Professor, Department of Pharmaceutics, Axis Institute of Pharmacy, Kanpur, India.

Received: 2025-4-05 Revised: 2025-4-17 Accepted: 2025-4-25

**ABSTRACT**

Microneedle technology is a new and important way to deliver medicine through the skin. It provides a simple and less painful option compared to traditional methods like taking medicine by mouth or getting shots. Microneedles make tiny holes in the outer layer of the skin, allowing different medicines, including small chemicals, proteins, and vaccines, to be delivered easily and without pain. This review looks at different kinds of microneedles: solid, coated, dissolving, hollow, and hydrogel-forming. It also discusses how these needles are made, how they deliver medicine, and how they are used in healthcare. The advantages of the technology, like better patient adherence, avoiding the body's first breakdown of medicine, and the possibility for people to take it themselves, are explained in detail. The review also talks about current problems in making products on a large scale, keeping drugs stable, and getting approval from regulators. It points out future possibilities like smart microneedles and combining technology with digital health systems. In general, microneedle technology is a big improvement in how drugs can be delivered through the skin. It could change the way we use modern medicine and tailor treatments to individuals.

**Keywords:** Minimally Invasive Systems; Controlled Drug Release; Dissolving Microneedles; Patient Compliance; Biomedical Applications.

## INTRODUCTION

Microneedle technology is a new way to deliver medicine through the skin. It is less painful and more effective than traditional methods like taking pills or getting shots[1]. Human skin acts as a natural shield that protects us from outside substances. However, this protective quality also makes it hard for many medicine types, especially large molecules like proteins, peptides, and vaccines, to get through the skin. Traditional transdermal patches work by allowing medication to pass through the skin on its own. This method only works well for small, fat-friendly drugs, which limits the types of medicines that can be delivered this way. Microneedles make tiny holes in the skin, which helps medicine get past the top layer of skin and into deeper layers, where it can be easily absorbed into the bloodstream.

Microneedles were first thought of in the 1970s, but in recent years, a lot of research and new technology have made them a useful way to deliver medicine. Microneedles are small, needle-shaped tips that are usually between 50 and 900 micrometres long[2]. They are made to gently go into the skin without causing pain. Unlike regular needles, these don't go deep into the skin where nerves and blood vessels are. This makes getting an injection almost painless and helps lessen the fear of shots. This feature helps patients follow their treatment plans better, especially for those who need to take medicine often, like diabetics who require insulin shots or people with long-lasting illnesses.

One big benefit of microneedle technology is that it can deliver many types of treatments, like small drugs, biological products, genetic material, and vaccines. This is especially helpful for things like vaccination programs, where it's important to make it easy to give the vaccines and for patients to follow through. In the last few years, using microneedles to deliver COVID-19 vaccines has become popular because it could make giving out and giving the vaccines easier[3]. Also, microneedles are being looked at for beauty and skin treatments, like delivering anti-aging ingredients, acne medications, and targeted drug therapies for skin problems.

Different kinds of microneedles have been created, such as solid, coated, dissolving, hollow, and hydrogel-based microneedles. Each type works in its own way and is meant for particular uses. Methods like lithography, micromolding, laser cutting, and 3D

printing have made it possible to produce microneedles in large amounts while carefully controlling their size, shape, and how much medicine they can hold[4]. Even with these improvements, there are still problems to solve, like finding affordable ways to make large amounts of microneedles, ensuring they stay stable over time, and dealing with rules and regulations before they can be widely used in medicine.

**Microneedle Technology: An Overview**

Microneedle technology is a new way to deliver medicine through the skin that solves the problems of traditional methods like taking pills or getting shots. This new system uses tiny needles to gently go through the top layer of the skin[5]. It delivers medicine without going too deep, which helps to reduce pain and lowers the chance of infection.

Usually, getting medicine through the skin has been difficult because the outer layer of skin blocks larger drugs and proteins from passing through. Transdermal patches are commonly used to deliver small, fatty drugs, but they do not work well for water-friendly substances and large molecules. Microneedles are a good option because they make tiny holes in the skin, which helps more medicines get into the bloodstream.

The design of microneedles has changed a lot, with various kinds made for different uses[6]. Solid microneedles make tiny openings in the skin to help medicines get absorbed better when applied afterward. Coated microneedles have a layer of medicine on them that melts when inserted into the skin. Dissolving microneedles are made from special materials that break down over time. They hold the medicine inside and slowly release it as they dissolve. Hydrogel microneedles expand when they touch the skin, which helps release medicine slowly. Hollow microneedles act like small tubes to bring liquid medicine into the skin.

Ways to make microneedles include using techniques like lithography, micromolding, and 3D printing. These methods allow for the production of many microneedles with great accuracy[7]. These improvements have increased their use in medicine, especially for delivering vaccines. Microneedles help boost the immune response while being gentle on the skin. Giving insulin to diabetic patients is another focus, providing a way that is less painful and easier than regular skin injections. Also, microneedles are becoming popular in skincare and beauty treatments for issues like acne, dark spots, and signs of aging[8].

Besides medicine, microneedles show promise in wearable health sensors that allow for continuous health tracking, making them an important part of personalized healthcare[9]. Even though there are many benefits, there are still problems with making sure each batch is the same, keeping drugs stable, and getting the necessary approvals to use them widely.

As research goes on, new ideas like smart microneedles with sensors and controlled medicine release are changing the future of skin treatments. Microneedle technology is changing how medicines are given. It offers a future where treatments can be pain-free, easy to do by yourself, and very effective.

**Types of Microneedles**

Microneedle technology is a new and better way to deliver medicine through the skin. It helps overcome the problems that come with regular skin patches and needle injections. Microneedles are very small needles, usually between 50 and 900 micrometres long, that can go through the top layer of the skin without causing pain. This helps deliver medicine into the bloodstream. Different kinds of microneedles have been created, all aimed at making medicine delivery better, being safe for the body, and ensuring that patients will use them.

Solid microneedles are one of the first designs used to make tiny holes in the skin to help medicine get through better[10]. These tiny needles are used on the skin and taken out before putting on a skin medication. The tiny channels created help more medicine pass through the skin. Solid microneedles work well, but they need another step to apply the medicine, which might make it harder for patients to follow through.

Coated microneedles are better than solid microneedles because they have a layer of medicine applied directly to their surface[11]. These tiny needles help release medicine when they are put into the skin because the outer layer dissolves in the fluid around the cells. The coating process helps place the right amount of medicine on a surface, but there are problems to solve, like making sure the coating is even and that the right amount of medicine is used, to provide steady medicine delivery.

Dissolving microneedles are a new way to deliver medicine. These microneedles are made from special materials that can break down in water and are safe for the body[12]. When these tiny needles are put into the skin, they dissolve completely and release the medicine inside into the body. This method removes worries about tiny needle leftovers in the skin, making it safer and encouraging

patients to follow treatment better. Also, dissolvable microneedles allow for controlled release of medicine by changing the materials used in them. However, we need to improve their stability and ability to hold drugs.

Hydrogel microneedles are a new type of needle that expands when they touch the moisture in your skin[13]. This helps them release medicine slowly over time. These microneedles are made from special gel materials that hold medicine, letting it slowly enter the blood. Hydrogel microneedles have benefits like releasing medicine slowly and causing little irritation to the skin. They are especially good for carrying large medicine molecules, like peptides and proteins. But scientists are still studying their strength and how well they last over time.

Hollow microneedles have a tiny hole in the middle that allows liquid medicine to be sent through them[14]. These microneedles work like regular needles but they are much smaller, which makes them hurt less and feel more comfortable. Hollow microneedles allow for accurate dosing and real-time control of drug delivery, making them good for biologics and vaccines. Even though they have benefits, there are some problems, like the chance of needles getting blocked, complicated ways to make them, and the need for extra tools to deliver medicine, like pumps that use pressure.

Every kind of microneedle has its own strengths and weaknesses, which makes them good for different treatments. The ongoing development of microneedle technology aims to make medicines easier to absorb, improve comfort for patients, and allow people to take their own medications[15]. Future studies will aim to improve material qualities, allow more medicine to be packed in, and combine smart technologies to create better and more personalized ways to deliver drugs. Microneedle drug delivery could change how we give medicine through the skin. It is a simple, effective, and easy way for patients to take medicine compared to traditional methods.

**Fabrication Techniques of Microneedles**

Microneedle technology is a new way to deliver medicine through the skin. It allows drugs to be given effectively and with little discomfort. Making microneedles is very important because it affects how well they work, how strong they are, and how well they deliver medicine. Different methods have been created to make microneedles that are the right size, have sharp points, and are safe to use in the body[16]. These methods include making things using printing techniques, moulds, cutting with lasers, and 3D printing. Each method has its own benefits based on the type of material and what it's going to be used for.

Lithography-based fabrication is a common method, especially for making microneedles from silicon and metal. This method uses photolithography, where a light-sensitive material is shaped by using a mask to make microneedle structures. Silicon microneedles made using a special process called deep reactive ion etching (DRIE) are very accurate and strong[17]. This makes them good for delivering medicine that needs to be sturdy. But the high price and weakness of silicon make it hard to use a lot in business situations.

Micromolding is a common technique, especially for making tiny needles from polymers and materials that can dissolve[18]. In this process, a main mould is made, usually using special techniques like lithography or micromachining. This mould is then used to create microneedle arrays by pouring liquid plastics or drug-filled materials into it. After they are dried, the microneedles are gently taken out while keeping their shape and medicine inside. This method is cheap and makes it easy to produce a lot of biodegradable microneedles that dissolve in the skin and release the medicine slowly.

Laser cutting and engraving methods are also used to make microneedles, especially those made of metal and plastic[19]. Laser micromachining is a method that provides very accurate cutting and can work on various materials. It creates sharp tips on microneedles, which are needed for effective skin penetration. This method is good for quickly creating and customizing microneedle arrays, but it might not work as well for making a lot of them at once like micromolding does.

The development of 3D printing has opened up new ways to make microneedles. This method allows the building of microneedles one layer at a time, with precise shapes and complex designs that were hard to make with older techniques. Methods like stereolithography (SLA) and two-photon polymerization (TPP) have been studied for making microneedles with complex designs that are made for specific ways to deliver medicine[20]. The main problem with 3D printing is that the tiny needles it makes might not be very strong or detailed. They might need extra work after printing to make them tougher.

Each way of making microneedles has its pros and cons based on the kind of microneedles and how they will be used. For example, solid and hollow microneedles usually need strong materials and careful making methods like lithography or laser cutting[21]. On the other hand, dissolving and hydrogel-based microneedles work well with micromolding and 3D printing methods. The way microneedles are made affects how strong they are, how much medicine they can hold, and how well they work for delivering medicine through the skin. As research progresses, using different making methods and discovering new materials will improve microneedle technology, which will help it be used more widely in medicine and drug delivery.

**Drug Delivery Applications of Microneedles**

Microneedle technology is a new and effective way to deliver medicine through the skin. It addresses the problems that come with regular patches and needle injections. These tiny needles gently go through the outer skin layer, making it easier to use different medicines and helping patients to stick to their treatment[22]. This technology has been studied a lot for delivering medicine, especially in situations where regular methods have problems, like when skin doesn't absorb the medicine well, people are afraid of needles, or when medicine needs to be taken often[23].

One of the most important uses of microneedles is for giving vaccines. Regular vaccines usually need to be kept cold and given by trained people, which can be hard to manage, especially in faraway places. Microneedle patches are a way to get medicine without using a needle. This means people can use them by themselves without needing help from medical professionals. Many studies have shown that using microneedles to deliver vaccines works well for influenza, measles, and more recently, COVID-19[24]. These patches can improve the immune system by focusing on certain skin cells that help present antigens, which makes the vaccines work better even with smaller amounts. Also, microneedles can help create vaccines that don't need to be kept in the fridge, making it easier for people around the world to get them.

Another important use is in managing diabetes, especially for giving insulin. Insulin shots are painful and need to be given often, which makes it hard for people to stick to their treatment[25]. Microneedles provide a simple way to deliver insulin without much pain and with good control. Researchers have studied tiny needles that contain insulin. These needles dissolve when they go into the skin, which helps keep blood sugar levels steady and manageable[26]. Some new developments have combined tiny needles with materials that react to blood sugar levels, allowing insulin to be released when needed. This makes managing diabetes easier and more convenient for patients.

Microneedles might be useful for managing pain and numbing specific areas. Regular anaesthetic shots, like lidocaine, can hurt and need to be given by a trained person[27]. Coated or dissolving microneedles help deliver medicine quickly to specific areas, giving pain relief in a controlled way. This application is especially helpful in skin care and small surgeries, where quick pain relief is important and people want to feel as little discomfort as possible[28].

Besides medicines, microneedles are also being noticed in beauty and skin care. They are commonly used to deliver anti-aging products, acne treatments, and skin lighteners through the skin. Microneedles help large molecules like hyaluronic acid and peptides to easily enter the skin, providing a painless way to refresh and improve the skin. This method is very popular for treating wrinkles because it helps the good ingredients get deeper into the skin without needing needles or complicated steps[29].

The technology has also been looked at for delivering biologics, like peptides, proteins, and RNA medicines[30]. Because these large molecules usually do not absorb well into the skin and break down quickly in the digestive system, microneedles provide a good option instead of taking medicine by mouth or getting injections. Many studies have looked into using microneedles to help deliver treatments like monoclonal antibodies, gene therapy, and mRNA medicines. These methods have shown better absorption and precise delivery of these treatments.

Microneedle technology can greatly change how medicines are delivered for different types of treatments. It can help medicine get absorbed better, cause less pain, make it easier for patients to follow treatment, and allow people to give themselves the medicine. This makes it a good choice compared to regular ways of taking medicine. As technology keeps improving, microneedles might lead to better, cheaper, and easier medical treatments for patients in the future.

**Pharmacokinetics & Mechanism of Action**

Microneedle technology is a new and helpful method for giving medicine through the skin, especially for drugs that usually have a hard time getting through the skin. It's important to understand how this technology works and how the body processes it to see its value and how well it can help people.

The stratum corneum is the top layer of the skin, and it makes it hard for many drugs to pass through, especially those that are heavy or not very oily[31]. Traditional transdermal systems often have trouble getting drugs through the skin, which restricts their use to only a few types of drugs. Microneedles solve this problem by making tiny holes in the outer skin layer, which allows drugs to reach the deeper layers of the skin where blood vessels can help absorb them.

When used, microneedles gently go into the skin a little bit without hitting nerves or blood vessels, so it doesn't hurt much or make you bleed. This lets the medicine either spread into the skin layers by itself or be pushed in with help, depending on the type of microneedle used. For example, in coated microneedles, the medicine is put on the outside of solid microneedles and quickly melts

after they are inserted. Dissolving microneedles are made from materials that break down naturally. They hold medicine inside and let it go into the body as the microneedles dissolve in the fluid around cells[32]. Hollow microneedles can put liquid medicine straight into the skin, which helps the body absorb it quickly.

Using microneedles to deliver drugs can greatly change how fast and how much of the drug gets absorbed into the body. Bypassing the outer layer of the skin makes it easier for drugs that usually don't absorb well through the skin to be more available for use. The effects can start quicker than regular skin patches, sometimes similar to shots under the skin, especially with hollow or fast-dissolving microneedles[33]. Also, microneedles can be designed to release the medicine slowly and steadily, depending on how they are made and what materials are used. This can be very helpful for keeping drug levels in the blood stable, which helps the medicine work better and makes it easier for patients to stick to their treatment.

How drugs move from microneedles into the skin depends on several things, like how easily the drug dissolves, the size of its molecules, how wet the skin is, and the design of the microneedles. Drug movement through the skin follows Fick's law of diffusion, and the size and thickness of the microneedles can change how fast the drug spreads. Also, the blood flow in the skin layer helps the medicine get into the bloodstream[34]. Microneedle technology reduces the breakdown of drugs in the body before they work, which is a big benefit compared to taking medicine by mouth.

Microneedle drug delivery works better than traditional skin patches in how the medicine is absorbed and how it acts in the body. Microneedles help drugs pass through the skin easily and in a controlled way. They offer a new and user-friendly method for treating issues both all over the body and in specific areas[35]. This expands the possibilities of delivering medicine through the skin beyond what was usually possible.

**Safety, Biocompatibility, and Patient Compliance**

Microneedle technology is getting a lot of interest for delivering medicine through the skin. This is because it's not very painful, people can use it themselves, and it helps medicine get into the skin more easily. As technology moves from being studied in labs to being used in hospitals and businesses, making sure it is safe, works well with people's bodies, and that patients can use it easily is very important for it to be successful and accepted in healthcare.

Safety is very important when using microneedles to deliver medicine. Microneedles go into the top layer of the skin but don't go deep enough to hit pain nerves or blood vessels. This means there is much less chance of pain, bleeding, and serious side effects compared to regular needles.[36] But it's very important that microneedles are strong and stay in good shape. If microneedles break or don't go in all the way, materials can get stuck in the skin, which might cause irritation or swelling. So, choosing the right materials and testing their strength are very important when designing and making things. Most microneedles are made from safe materials like plastics, metals, or silicon. For dissolvable microneedles, materials like hyaluronic acid or polyvinylpyrrolidone are usually chosen because they break down easily, which helps prevent leftover substances in the skin.

Biocompatibility means how well the materials used for microneedles work with the body without causing any negative reactions. A biocompatible system makes sure that the device does not cause any strong immune reactions, allergies, or harm when it is used[37]. Many tests done on skin in labs and on animals show that most microneedle systems are safe and do not cause problems for human and animal skin. Biodegradable microneedles are good because they completely dissolve after use, so there's no sharp waste or leftover materials. However, to get regulatory approval, we need to carefully check for harmful effects, irritation, and long-term effects of breakdown products, especially when treatments are given multiple times.

Patients are more likely to follow their treatment plans when using microneedle systems compared to regular methods like injections. Using microneedles doesn't hurt much or at all, which makes people, especially kids and older adults, less scared and anxious about needles. Research has shown that many people are open to using microneedle patches for vaccines, insulin, and beauty treatments[38]. Also, it's easier to use and can be done at home, which helps people stick to their treatment plans and makes it less stressful for healthcare workers. This is especially helpful for long-lasting illnesses where people need to take medicine for a long time.

Even though microneedle systems have benefits, they still have problems that could make patients less willing to use them and might pose safety risks. Using the medicine incorrectly by untrained people, differences in skin types, and outside conditions can affect how well the medicine works. Also, groups like the FDA stress the importance of having consistent ways to apply products and strong quality checks to ensure they work well every time[39].

Microneedle technology is a promising way to deliver medicine through the skin. It is safe, works well with the body, and is easy for patients to use. As clinical studies and rules keep changing, current research shows that it can be very useful in different areas of treatment, as long as production and use are done carefully and meet high standards.

**Challenges and Limitations**

Microneedle (MN) technology has great potential to change how medicines are delivered through the skin. It provides a simple, painless, and effective way to treat both whole body conditions and specific areas. Even with these benefits, there are many challenges and limitations that make it hard to widely sell and use it in hospitals[40].

One of the main problems is making and producing microneedles in large amounts. Making dissolving and hollow microneedles involves careful and accurate work, along with special materials. Making sure that microneedles are all the same size, shape, and amount of medicine they hold when producing them in large quantities is difficult and can be expensive. Also, based on how they make things (like micromolding, 3D printing, or lithography), the cost of production might be too high for use in places with limited resources.

One big problem is how much medicine can be added. Because microneedles are small, they can usually hold only a small amount of medicine. This may not be enough for treating conditions that need larger doses. This limits their use to strong medicines that need very small amounts, like micrograms or low milligrams. Also, some biologics or large molecules can have stability problems when they are made, stored, or used, especially if they are exposed to heat or moisture during these processes.

There are also worries about how strong the material is and how well it can be inserted into the skin. Microneedles can reliably go through the outer skin layer without bending or breaking based on things like the material they are made of, their shape, and how they are put in. Materials like polymers used in dissolving microneedles might not be strong enough to insert properly into the skin every time[41]. This can result in not delivering the medicine fully or the device not working as it should. Sometimes, putting the medicine in by hand can lead to uneven depth, which can change how well the medicine works.

Differences between patients make it harder for microneedles to work well. People have different skin types, thickness, moisture levels, and flexibility, and these differences can affect how well microneedles go into the skin and how well they deliver medicine. This variation makes it harder to create standards and find the right dose, especially when trying to distribute the medicine throughout the body.

From a rules-making point of view, microneedle technology brings new difficulties for approval organizations like the FDA or EMA. Since MN systems usually include parts of both medical devices and drugs, the rules for approval are more complicated[42]. Right now, there are no widely agreed-upon rules for the safety, effectiveness, and quality of microneedle products. This makes it harder for these products to get approved and sold.

Teaching patients and getting them to accept the device are important too. Microneedles are usually easy to use, but people need to be trained, especially when they are giving the treatment to themselves[43]. Using the wrong methods may cause the device to not work properly or the treatment to be ineffective. People might worry about skin irritation, infections, or leftover material in their skin, which can stop them from using it, especially if they have sensitive skin or a weak immune system.

While microneedle technology is a big improvement for delivering drugs, there are still many technical, regulatory, and user issues that need to be solved before it can be widely used[44]. Continuing research, new ideas in materials and design, and teamwork between schools, businesses, and regulatory agencies are important to solve these problems and fully realize the benefits of microneedle drug delivery systems.

**Future Perspectives and Innovations**

The future of microneedle technology for delivering drugs through the skin looks very promising. This is due to fast improvements in materials, medical engineering, and digital health tools[45]. Microneedles have already shown great promise in delivering various medicines, but future improvements aim to make them work better, use them for more purposes, and make them easier for patients around the world to get. As scientists keep looking for new materials and ways to make things, the next types of microneedles are likely to be more accurate, adjustable, and easier for patients to use.

One of the most hopeful areas in microneedle technology is making smart microneedle systems. These are made to react to certain body conditions like acidity, heat, or sugar levels, allowing for precise and timely release of medicine. For example, special tiny needles that respond to glucose levels are being studied to give insulin to diabetic patients automatically. This could mean they won't need to check their sugar levels or get shots as often. This combination of sensing and delivery methods is a big step toward personalized medicine, where medication is given based on each patient's needs right when it's needed.

Another cool new idea is using small microneedle patches that you can wear, along with digital health apps. These devices can keep track of a patient's vital signs while giving them medicine, making it possible to treat them from a distance and automatically. For long-term conditions like high blood pressure or hormone shortages, this type of system can help people stick to their treatment and improve their health results. Also, microneedle patches can work with smartphones or wireless devices to gather and send data. This allows doctors to check how patients are doing from a distance and change treatments if needed.

Biodegradable and eco-friendly microneedles are becoming more popular. Future designs will probably use eco-friendly materials that cut down on medical waste and get rid of the need to dispose of sharp objects. Natural or specially-made polymers that break down safely in the body can improve safety and help with large-scale production, especially in places with limited resources. Researchers are also working on tiny needles that can give complex medicines like mRNA vaccines, DNA pieces, and special antibodies. This could lead to new ways to treat diseases and improve immune responses[46].

The beauty and skin care industry is exploring new uses for microneedle technology. This could lead to better ways to deliver anti-aging treatments, improve skin health, and create custom skin care plans. Using artificial intelligence, microneedle patches can be made to check skin problems and provide treatments that are specially made for each person's skin type and condition[47].

These new ideas look good, but for many people to use them, we need to solve some problems like making them in large amounts, getting permission from the government, and keeping costs down. But teamwork between universities, businesses, and government agencies is helping to speed up the process of turning research into medical treatments. Microneedle technology is being studied and developed to change the way we deliver medications through the skin. It will also improve personalized medicine and less invasive medical procedures. Microneedles can connect regular medicines with new digital treatments, giving patients safer, smarter, and easier ways to get care.

**Conclusion**

Microneedle technology is a new and exciting way to deliver medicine through the skin. It provides a better option than traditional methods like taking pills or getting shots with needles. This technology solves important problems with regular skin patches, which often have trouble letting medicine through the skin because of its natural barrier, especially the outer layer. By creating micro-scale pathways in the skin without reaching the pain receptors, microneedles facilitate the efficient and painless delivery of a wide range of therapeutic agents, including small molecules, proteins, peptides, and even vaccines.

One of the biggest benefits of microneedle systems is that they are not very invasive. This makes it easier for patients to use them, especially for those who are sensitive to pain from needles, like children and older adults. Their design allows people to use them on their own, which cuts down on the need for healthcare workers and facilities. This is particularly helpful in places where resources are limited. Microneedles work quickly and do not go through the liver first, which makes them great for drugs that don't work well when taken by mouth. The different types of microneedles—solid, coated, dissolving, hollow, and hydrogel-forming—can be customized to control how fast or slow the medicine is released. This helps improve treatment results.

In making medicine, microneedle technology can be made using different methods like lithography, micromolding, laser cutting, and lately, 3D printing. These methods allow us to make microneedles from different materials, like metals, plastics, and materials that can break down naturally. This means we can use them in many more ways. Recently, dissolving microneedles have become popular because they are safe. They completely dissolve after being used, so there’s no risk of dealing with sharp waste or leftover needle pieces.

Microneedles have shown promise in many uses, such as delivering vaccines, giving insulin, treating cancer, and helping with skin conditions. Their ability to provide treatments like monoclonal antibodies and genetic materials like mRNA has created new opportunities, especially with recent progress in genetic and personalized medicine. Also, they are important in skin care and beauty treatments, like anti-aging products and skin patches with medicine. This makes them useful in areas beyond regular medicine.

Even though microneedle technologies show a lot of potential, they still have some problems to overcome. This includes the need for affordable and flexible manufacturing, having clear rules, and thorough testing to make sure that products are safe and effective for different groups of patients. The stability of some drugs in microneedle products, especially biological ones, is very important to think about. Also, differences in patients' skin and the chance of not inserting properly or giving uneven doses should be looked into more with additional research and improvements in technology.

In summary, microneedle technology is about to change how medicines are delivered, making it easier, more effective, and better for patients. As research keeps solving current problems and improving how treatments are given, microneedles are likely to be very important in the future of non-invasive therapies. As more schools, companies, and government agencies focus on them,

bringing these ideas into regular healthcare seems possible and likely. They could greatly change how medicine and patient care work.

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How to cite this article:
Sagar Singh et al. Ijppr.Human, 2025; Vol. 31 (4): 324-332.

Conflict of Interest Statement: All authors have nothing else to disclose.