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REVIEW ARTICLE **OPEN ACCESS**

Microneedles for Transdermal Drug Delivery System: A Review

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ABSTRACT
The transdermal route has been studied for a variety of drugs because it avoids the first-pass effect and allows for continuous drug release. Many drug substances have become found difficult to deliver through the skin due to the skin's strong barrier property, especially the stratum corneum. On the other hand, hydrophilic compounds and macromolecular agents like peptides, DNA, and small interfering RNA can be difficult to transport. Drug penetration into the stratum corneum may be accomplished through bypass or reversible disruption of the stratum corneum layer. The use of micron-scale needles helps to improve skin permeability, which has recently been proposed and proved to greatly increase permeation, particularly for macromolecules. Microneedles can reach the viable epidermis through the stratum corneum layer of the skin, avoiding nerve fibres and blood vessels in the dermal layer. The types of microneedles and their designs, as well as the materials utilized in fabrication and manufacturing procedures, are discussed in this paper.
Keywords: *Microneedle; Transdermal drug delivery; First pass effect*

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INTRODUCTION

To administer drugs and vaccines to the skin, microneedle patches include hundreds of microneedles spaced less than one millimetre apart. The patch is made up of a series of microneedles attached to an adhesive backing that allows it to be applied to the skin easily. Due to the anticipation of ease of administration, good skin tolerability, and significant patient acceptance, microneedle patches are being developed as an alternative to traditional needle-and syringe injections [1]. It's also a painless and less intrusive procedure that allows the medicine to flow right through the stratum corneum, the skin's greatest barrier [2]. Many medications are unable to pass the skin at the requisite rate for therapeutic effect, which is a major issue with transdermal technology. Scientists have created microneedles as an improved strategy for allowing hydrophilic high molecular weight substances to infiltrate the stratum corneum. Drug molecules can pass the stratum corneum layer when administered with a microneedle device, allowing more drug molecules to enter the skin. The rapid onset of action, better patient compliance, self-administration, enhanced permeability, and efficacy are all characteristics of this technique [3]. Microneedles are similar to ordinary needles, however, they are fabricated on a micro level. They are typically 1 µ in diameter and range in length from 1-100 µ. Metals, silicon, silicon dioxide, polymers, glass, ceramics, and carbohydrates have all been used to make microneedles[4]. We cover the requirements for microneedle design, fabrication materials, and several microneedle fabrication techniques in this paper, along with, recent biological applications.

MECHANISM OF DRUG DELIVERY

"The drug is delivered employing the diffusion mechanism via the topical route. During the microneedle drug delivery mechanism, the skin is temporarily disturbed. Hundreds of microneedles are arranged in arrays on a tiny patch (similar to a conventional transdermal patch available on the market) to administer enough drug to give the appropriate clinical effects" [3]. It pierces the stratum corneum and passes through the barrier layer. The drug is injected directly into the epidermis or higher dermis layer, where it enters the systemic circulation and produces a therapeutic action once it reaches its target site [5]. The mechanism of drug delivery by microneedles is depicted in Figure 1.

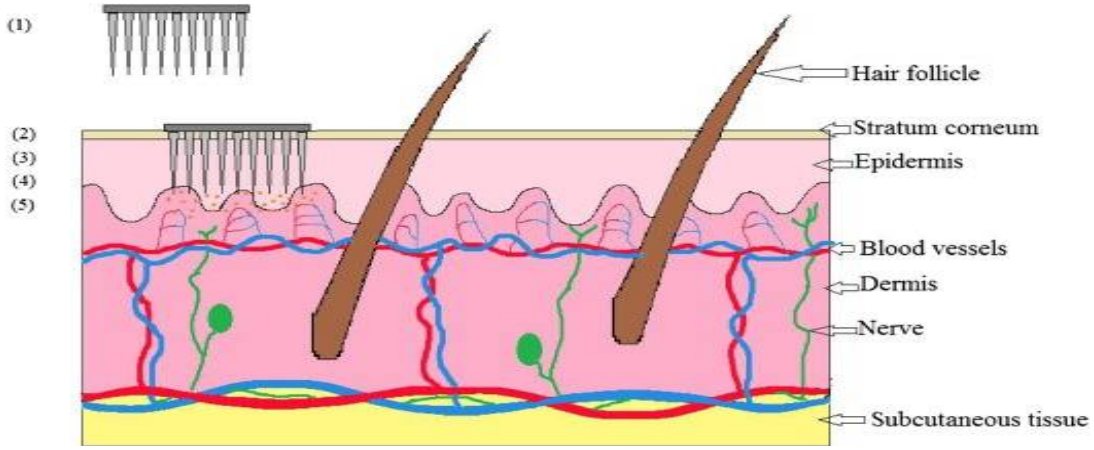

Figure 1: Drug delivery by microneedle device; (1) drug-loaded microneedle device; (2) device placed into the skin; (3) temporary mechanical rupture of the skin; (4) drug release in the epidermis; (5) drug transport to the site of action [3].

Dimensions of microneedles

Microneedles are available in a variety of sizes, depending on the type of microneedle and the material utilized. Because the epidermis can be up to 1500 µm thick and the needle can be up to 1500 µm long, the drug can be released into the epidermis with ease. Longer needles with a thicker diameter can penetrate deeper into the dermis, but they will damage nerves and create discomfort [6] (Williams and Barry, 2004). They usually have a length of 150–1500 µ, a breadth of 50–250 µ, and a thickness of 1–25 µ near the tip [5].

MICRONEEDLE FABRICATION MATERIAL AND ITS PROPERTIES

Silicon

In 1990, silicon was used to create the first microneedle [7] (Akhtar, 2014). Silicon is a crystalline compound that is anisotropic in nature. The crystal lattice orientation determines its properties, resulting in elastic moduli ranging from 50 to 180 GPa [8, 9]. Because of its flexibility, it may be used to make needles of various sizes and shapes. It is a versatile material due to its attractive physical features. Silicon substrates can be accurately manufactured and can be produced in batches. Silicon's high cost and complex fabrication process limit it from being used in microneedles. Due to its brittle nature, some silicon may break and remain in the skin, causing skin allergies, redness, and irritation, as well as biocompatibility concerns [8].

Metal

Stainless steel and titanium are the most commonly used metals. Also used are palladium, nickel, and palladium-cobalt alloys [10]. They have better mechanical properties than silicon and are therefore probably more suited for microneedle production. The first metal utilized in the manufacture of microneedles was stainless steel [11]. Titanium alloys are more expensive than stainless steel but, have greater mechanical strength [8].

Ceramic

Chemical resistance is the primary benefit of alumina (Al_2O_3). It produces a stable oxide due to the highly energetic ionic and covalent bonds generated between the “Al” and “O” atoms. Calcium sulphatedihydrate [Gypsum ($CaSO_4.2H_2O$)] and calcium phosphate dihydrate [Brushite ($CaHPO_4.2H_2O$)] are two other types of ceramics used. In recent years, Ormocer®, an organically modified ceramic, has been employed, which is a three-dimensional cross-linked copolymer [3]. Using various organic units during polymerization can result in a polymer with different properties. Micro-molding is used to make the majority of them. A micro-mold can be easily cast with ceramic slurry. Micro-molding methods are less expensive and have the potential for scaling up [8].

Silica glass

Glass may be employed to develop a variety of geometries on a small level. glass is physiologically inert but fragile in nature [12]. More elastic is borosilicate glass, which is composed of silica and boron trioxide. They are usually made manually, thus they are less time efficient [3]. Glass microneedles are no longer utilized commercially and are mostly used for research due to their fragility [8].

Carbohydrate

One of the most widely used sugars is maltose among carbohydrates [13] (Lee, 2011). Other sugars and polysaccharides, such as mannitol, trehalose, sucrose, xylitol, and galactose, are also used [14] (Martin et al., 2012). Silicon or metal templates are used to make carbohydrate slurries. The drug-loaded carbohydrate mixture is poured into the moulds to make the microneedles[15]. Carbohydrates are cheap

and safe for human health, but they break down at high temperatures which makes them challenging to fabricate [8].

Polymer

To prepare the microneedles, a wide range of polymers such as "poly (methyl methacrylate) (PMMA), polylactic acid (PLA), poly (lactic-co-glycolic acid) (PLGA), polyglycolic acid (PGA), poly (carbonate), cyclic-olefin copolymer, poly (vinylpyrrolidone) (PVP), poly (vinyl alcohol) (PVA), polystyrene(PS), poly (methyl vinyl ether-co-maleic anhydride), SU-8 photoresist" [3]. These polymers are commonly used to make dissolving or biodegradable microneedle arrays, as well as hydrogel-forming microneedle arrays. These polymers create microneedles that are lower than metal and silica but tougher than glass and ceramics [8].

PENETRATION ENHANCERS

Penetration enhancers (also known as sorption promoters or accelerants) penetrate into the skin to reversibly lower barrier resistance, which is a long-standing method for increasing transdermal medication delivery. Several substances have been tested for their ability to improve penetration, such as water, sulphoxides, azone, pyrrolidones,fatty acids, surfactants, phospholipids, alcohols, essential oil, terpenes and terpenoids [6].

TYPES OF MICRONEEDLES

The many varieties of microneedles that have been created for use in drug delivery include solid, coated, dissolving, hollow, and hydrogel microneedles. Figure. 2. depicts various types of microneedles, each with its own set of properties. Each type of microneedle has a unique way of delivering the drug to the epidermis. Some are just employed to generate pores in the stratum corneum, while others are precoated, dissolvable, or prefilled with the drug solution on their surface [8].

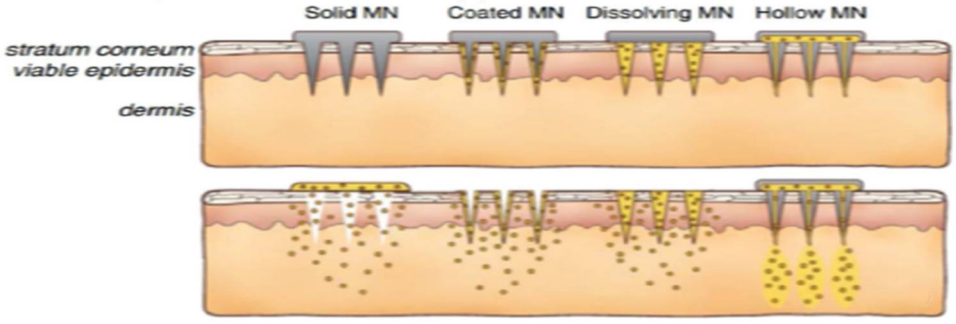

Figure 2: Microneedles of various structures and configurations [48] (Manoj and Manoj, 2019)

Solid microneedles

Solid microneedles are a collection of microscales tapered sharp ends constructed of a single material with no drugs or excipients. They are placed into the skin and create micron-sized pores on the surface of the skin [2]. When the drug is applied to the treated area, it passes through these pores and into the stratum corneum, the skin's largest barrier, where it is easily transferred to the superficial dermis' capillaries, increasing the drug's bioavailability [16]. The agent can be applied to the skin as a transdermal patch or as a topical cream [17]. By incorporating reagents that maintain the pores open for a longer period of time, drugs can be given over a longer period of time.

Hollow microneedles

A hollow bore is present in the centre of a hollow microneedle. The hollow bore bypasses the stratum corneum layer and creates a direct path into the epidermis' lower layers when put into the skin [18]. The main purpose of these microneedles is to deliver drug solutions to the skin [19]. These are exceedingly pricey to make and require the use of expensive micro manufacturing processes. These tiny needles contain a hollow bore, which allows drugs to be delivered at higher rates via pressure-driven flow or diffusion via the interior of well-defined needles [7].

Coated microneedles

Coated microneedles have a water-soluble matrix on the outside surface of a solid microneedle, which allows the drug to dissolve quickly into the skin following insertion [47]. The coating formulation must form a film on the surface of the microneedles and maintain adhesion during storage and insertion into the skin [20].The coating formulation should have sufficient viscosity to achieve this goal. The location of the coating formulation should be considered. In general, it is more cost effective to place the drugs only at the tip of the microneedle where it enters the actual skin. In dip coating, the drug-coated region can be regulated by varying the depth to which the microneedle is dipped in the coating formulation [21,22]. Controlling the surface tension of the coating formulation, which regulates the spread of the microneedle,

can be used to estimate the drug-coated area. The drug is coated microneedles dissolves quickly in the skin, resulting in a rapid onset of drug action. The coating thickness can be raised by repeating the coating technique; but, due to dose limits, it is not ideal for drug administration because it requires a higher dose [3].

Dissolving microneedles

These microneedles use biocompatible polymers such as polyvinyl alcohol [47], carboxymethyl cellulose [23], or sugars [15] which on insertion into the skin to release the drug and dissolve it into the systemic circulation, resulting in a controlled release. The drug is released when the needle or the coated needle dissolves [13]. The use of water-soluble materials and low-cost polymers are the main advantages. However, the deposition of polymers into the skin is one of the significant drawbacks. These are made using either a lithographic technique or a two-layered technique [24]. The drug and polymer are combined, and the resulting solution is allowed to pass through the array holes. The push and pull movement is applied to two plates that are parallel to each other. As the polymeric solution solidifies, it is allowed to pass into the plate below and the top plate, which is removed at the end after the dissolving microneedle has been fabricated, resulting in conical shaped microneedles that can be mostly used in administering influenza vaccine [25]. Wu et al. (2015), recently developed sinomenin-loaded dissolving microneedles using a specialized fabrication technique involving biocompatible polymers [26].

Hydrogel-forming microneedles

It is a microneedle that was recently developed technique. Microneedles are made from super-swelling polymers. The hydrophilic structure is made up of polymers, which allow it to absorb a large amount of water into its three-dimensional polymeric network. Because of the presence of interstitial fluid, these polymers swell when inserted into the skin. This creates channels to form between the capillary circulation and the drug patch. These microneedles are only used to disrupt the skin barrier prior to needling. When they swell, they act as a rate-controlling membrane. They can be any size or shape. The unique properties of such microneedles are their ease of sterilization and removal from the skin [27]. Migdadiet al.(2018), investigated the use of hydrogel-forming microneedles to deliver metformin transdermally, reducing the gastrointestinal side effects associated with oral administration [28]. The use of specially developed microneedles increased the drug's penetration and bioavailability [29]. Swellablemicroneedles for drug delivery are also fabricated out of cross-linked polymers.

Fabrication techniques

The fabrication method for microneedles is classified by the characteristics, geometry, and material of the microneedles. Table 1 depicts various techniques used for various types of microneedles.

METHODOLOGY OF DRUG DELIVERY

To use microneedles for transdermal drug delivery, a variety of delivery strategies have been developed. These are some examples:

1. "Poke with patch" approach (Oligonucleotide delivery)
2. "Coat and poke" approach (Protein vaccine delivery)
3. Biodegradable microneedles
4. Hollow microneedles (Proteins,vaccines,and oligonucleotides)
5. "Dip and scrape" (DNA vaccine delivery)

Poke with patch approach

It involves piercing the skin with a number of solid microneedles and then applying the drug patch to the treated area. If an electric field is produced, drug transport over the skin can occur via diffusion or iontophoresis.

Coat and poke approach

In this method, needles are coated with the drug before being inserted into the skin for drug release via dissolution. The entire drug to be administered is coated on the needle.

Biodegradable microneedles

It involves encapsulating the drug within biodegradable, polymeric microneedles before inserting them into the skin for controlled drug release.

Hollow microneedles

It involves injecting the drug through a hollow bore needle. This method is more similar to (suggestive of) an injection than a patch.

Dip and scrape

The dip and scrape method is in which the microneedles are first dipped into a drug solution and then scraped across the skin surface, releasing the drug within the needle-created micro-abrasions.

EVALUATION OF MICRONEEDLES

Dimensional evaluation

To evaluate the needle geometry and measure the tip radius, length, and height of the microneedle, various methods are used. Optical or electrical microscopy is the most commonly used method. The analysis of a 3D image provides a more accurate image of needle geometry and helps in quality control. This was accomplished using scanning electron microscopy (SEM), transmission electron microscopy (TEM), and confocal laser microscope [30].

Mechanical characterization of microneedles

The mechanical properties of microneedles must be determined in order for them to penetrate the tissue. It considers the impact of mechanical forces on the needle during insertion into tissue. Table 2 lists the mechanical tests that were done on microneedles.

Stability study

The drug-coated arrays were heat sealed individually in foil pouches (Oliver Tolas, Grand Rapid, MI). The pouches were then stored for 4 weeks at 40°C/ 75% relative humidity (RH) or 28 weeks at 25°C/60% RH. After 4 weeks or 28 weeks, the samples were pulled from the stability chambers. Five samples were used for appearance evaluation and drug content, and five samples were used for in-vivo release for each set of the study. Unless otherwise mention stability study has to be carried out as per ICH guidelines.

In vitro skin permeation studies

To determine drug penetration through the skin, a vertical Franz diffusion cell device is performed. The experiment generally uses pig ear skin, which is positioned between the receptor and donor compartments. The cumulative permeation profiles of skin that has been micro needled and skin that has not been micro needled are compared [31].

In vivo animal model studies

The study can make use of hairless rats. To anaesthetize the animal, a suitable technique must be used. One of the parameters considered is Trans-epidermal water loss (TEWL), which is measured before and after micro needling. This parameter is measured using a DelfinVapometer. Other tests on designed microneedles include sterility studies, drug content, in-vitro release tests, and biocompatibility studies.

APPLICATIONS

Microneedles for vaccine delivery

People increased vaccination awareness has prompted scientists to implement new and more effective vaccine delivery methods. The most recent is microneedle drug delivery, in which the antigen is introduced directly into the dermis. As a result, an immune response can be achieved, and vaccination therapy can be completed. This activity is mostly carried out by dissolving microneedles. This process can be carried out using a variety of techniques and devices such as "mantoux" or "soluvia microinjection system." According to studies, mantoux technique is difficult to perform because it requires a professional, whereas soluvia technique is commonly used, and that too for the delivery of influenza vaccines, such as trivalent or quadrivalent or influenza type A or B [32-34].

Microneedles for insulin delivery

Various scientists, such as [16], conducted numerous experiments on insulin delivery and discovered that the insulin delivered by microneedle drug delivery was appropriate, generated proper biological effects, and maintained blood glucose levels. Insulin was also found to have proper bioavailability, since it was delivered into the body by coating it on a microneedle that punctured the stratum corneum layer, resulting in insulin delivery. The first method for delivering insulin was to use 10-IU standardized insulin lispro, which had a high absorption rate [32].

Microneedles for delivery of parathyroid hormone

It's used to deliver teriparatide, a kind of parathyroid hormone. It employs drug-coated microneedles that administer the drug after insertion in the skin, i.e., the drug coated microneedles dissolve after insertion. The use of a microneedle to deliver parathyroid hormone is not yet approved. However, it has undergone phase 1 and 2 trials, which found that the drug delivered by microneedles reached maximum concentration three times faster than the drug delivered via the conventional route [32]. Patches for the parathyroid have also been developed [35].

Microneedles for the administration of Lidocaine and other anaesthetics

The microneedles used in this study were both solid and hollow. The anaesthetic drug was administered to the various study participants, and the results, such as pain and numbness, were evaluated. The results showed that the pain was less than that of a traditional needle, and the numbness obtained was just as effective as the traditional method of approaching numbness to a specific part. As a result, it was concluded that microneedles were more effective than hypodermic needles in producing more numbness and less

pain, which worked to the benefit of the patient [32]. A solid-based microneedle has been developed for the delivery of lidocaine to anaesthetized patients [36].

Microneedles for cosmetic purposes (Dermabrasion)

Microneedles are used to remove scars, wrinkles, and other imperfections from the skin. This is accomplished by repeatedly puncturing the skin with microneedles, as opposed to the previous method of using a hypodermic needle. The pores created by microneedles resulted in increased collagen growth and the breaking or disruption of old collagen, causing skin damage. This resulted in wrinkle reduction and also helped in the treatment of acne. Dermaroller® is a special instrument designed for this purpose. It measures 12 cm in length and is made up of 192 miniature needles arranged in 24 circular arrays. The length ranges from 0.5 to 3 mm, and the diameter ranges from 0.1 to 0.25 mm. These needles can be adjusted based on the depth and skin layer in which they are used [32, 37,38].

Microneedles for naltrexone

Microneedle patches have been used to treat both opioid-dependent patients and alcohol addicts. When patches were used, researchers discovered that the optimum plasma level was reached within 2 hours of application and that the effect is prolonged for 72 hours. Thus, naltrexone-coated microneedles carried the drug into systemic circulation, helping to counteract the opioid effect [32].

Microneedles for acne scar treatment (Dermaroller)

Microneedles are used to cure acne scars. Anesthetic is applied to the acne scarred area, and the "Dermaroller" is employed, which can move in both vertical and horizontal directions. The saline pads are used to treat bleeding that has been controlled. The entire procedure takes 20 minutes to complete. Dermarollers for home use are also used to deliver anti-aging products [39].

Microneedles for glucose monitoring

Microneedles are used to indirectly monitor glucose levels. Previously, devices such as the "Cygnus glucowatch" were more commonly used to monitor glucose levels in the body [40]. Using silicon microneedles provided proper precision and needle penetration, allowing for the extraction of interstitial fluid with minimal pain and allowing for the monitoring of blood glucose levels. Kumetrix® is a commercially available glucose monitoring/sensing device made of silicon microneedles [41, 42].

Microneedle patch for iron deficiency anaemia

The success in modulating microneedle patches to replace the traditional methods of using iron supplements and parenteral approaches for treating iron deficiency in humans was achieved by using a micro molding technique, which helped to treat anaemia in patients without causing any gastric side effects. A rapidly dissolving type of microneedle loaded with ferric pyrophosphate was developed to aid in the treatment of iron deficiency anaemia. Satisfactory results were obtained from in vivo and in vitro studies [43].

Microneedles for transdermal protein delivery

Microneedle devices were created using a continuous liquid interface production technique and a polyethylene glycol base for effective protein delivery of serum albumin and ovalbumin. To avoid damage to the encapsulated protein, which may eventually result in immunogenicity as a result of exposure to the free radical polymerization procedure which is used to fabricate Continuous Liquid Interface Production-based microneedles. The solution was used to coat microneedles after the fabrication process was completed. The successful delivery was observed in 72hours studies on mice, where sustained protein retention was observed [44].

Ocular delivery

Targeted drug delivery can be used to treat a wide range of posterior segment indications. Nanoparticles were delivered through the suprachoroidal space using iontophoresis. The particles were found to localise at the injection site in the absence of iontophoresis. More than 30% of nanoparticles were delivered into the posterior segment of the eye when combined with microneedles [44].

Advantages of microneedles

1. The main benefit of microneedles over conventional injections is that they are inserted into the skin, they bypass the stratum corneum, which is a dead tissue with a thickness of 10-15 μm (Henry et al., 1998). Conventional needles that pass through this layer of skin can deliver the drug successfully, but they can also cause infection and pain. Microneedles, on the other hand, can be made long enough to pierce the stratum corneum while remaining short enough to minimize puncturing nerve endings. As a result, the likelihood of pain, infection, or injury is decreased.
2. Thousands of needles can be manufactured on a single wafer due to their modest size when fabricated on a silicon substrate. This results in great precision, reproducibility, and a significantly lower fabrication cost [45].
3. Hollow, similar to a syringe needle; solid, which increases permeability by poking holes in the skin and releasing the drug over the area; or drug can be coated on needles [49].

4. Using simple diffusion or acts on pump systems, arrays of hollow needles can be used to continually transport drugs into the system.
5. Hollow microneedles will help to remove fluid from the body for the estimation of blood glucose, based on that can be administered on microliter of insulin or other drugs as required.
6. Individual cells could be effectively drug administered using very small microneedles.
7. These are capable of delivering required dosing, complicated release patterns, on-site release, and biological drug stability enhancement by storing in a micro volume which can be precisely controlled.
8. Vaccination programmes in developing nations, such as mass immunisation or antidote administration in bioterrorism occurrences, could be carried out with basic medical training or experience [4].

Disadvantages of microneedles

1. It is possible to induce temporary irritation and allergy.
2. Advanced technologies are required for the production of a reproducible microneedle patch.
3. Microneedle patches require a storage container to keep them hygienically and damage free during their journey from fabricator to patient.
4. When using solid microneedles, some of the microneedles may break or remain in the skin, which can cause irritation and allergy [2].

Limitation

Due to their small size, microneedles can only deliver a limited number of drugs [2] (Jung and Jin, 2021).

Approved products

"Dermaroller" was the first microneedle product. Many microneedle products that have been approved for medical and cosmetic use are now available on the market. Table 3 contains a list of some of them. Many companies in Germany, the United States, Europe, and Japan sell microneedle products.

Table 1: Fabrication methods for various types of microneedles [3].

S.NO	Types microneedles	Fabrication techniques
1	Silicon microneedle	Silicon dry-etching process, Isotropic etching, Anisotropic wet etching, Dicing a silicon substrate and then acid etching. Three-dimensional laser ablation
2	Metal microneedle	Laser cutting, Wet etching and Metal electroplating methods
3	Polymer microneedle	Photolithography, continuous liquid interface production, microstereolithography and laser ablation.
4	Ceramic microneedle	Ceramic micro moulding and sintering lithography.
5	Coated microneedle	Dipping or spraying the microneedles with an aqueous solution of increased viscosity to retain more formulation during drying and which contains a surfactant, the active agent and a stabilizing agent. Microneedles can be dipped one time or more than one time into a coating solution, each individual microneedle can be dipped into a microwell containing drug solution or a film of drug solution previously formed on the roller can be applied. Layer-by-layer coating techniques.
6	Dissolving microneedle	Micro moulding
7	Hollow microneedle	Micro-electromechanical systems (MEMS) techniques-laser micromachining, deep reactive ion etching of silicon, and an integrated lithographic moulding technique, deep X-ray photolithography, electrochemical etching, wet chemical etching and micro-fabrication 3D printing(additive manufacturing).

Table 2: Testing for mechanical characterization

Parameter	Tests
Force of insertion	Dye marking, force displacement tests, and electrical measurements.
Insertion depth	Histological cryosectioning and staining, confocal microscopy and optical tomography.
Fracture force	Pressing the device on a rigid surface, displacement force tests.
Shear tests	Very accurate measurements could be achieved using a wire bond shear tester and Scanning Electron Microscope (SEM),

Table 3: Approved microneedle products [3].

Product name	Company name	Use
Dermaroller®	Dermaroller® Germany, White Lotus	Improve the texture of the skin, as well as scars and hyperpigmentation.
C-8 (Cosmetictype)	The Dermaroller Series by Anastassakis K.	Topical agents penetration is improved by using this method.
CIT-8 (Collagen Induction Therapy	The Dermaroller Series by Anastassakis K.	Used in collagen induction and skin remodeling.
MS-4	The Dermaroller Series by Anastassakis	Acne scars on the face are treated with this product.
MF-8 type	The Dermaroller Series by Anastassakis	Treatment for Scars.
MicroHyala®	CosMed transdermal drug Delivery	Treatment for wrinkles
LiteClear®	Nanomed skincare	Treats acne and skin blemishes
Soluvia®	Sanofi Pasteur Europe	Vaccination against influenza
h-patch	Valeritas	Drugs are delivered through subcutaneous tissue (insulin)
Microstructured transdermal System	3M	Biologics and other small molecules must be delivered.

CONCLUSION

Microneedles, in the form of a patch or an array, have been identified as a potential carrier for successful transdermal administration of a variety of macromolecular drugs. Microneedles are a transdermal drug delivery system that is rapidly gaining popularity in research due to the benefits of increasing patient access to drugs by replacing other routes of administration. Microneedle formulations include solid, coating, dissolving, and hydrogel formulations. They are made of a variety of materials, including silicon, metal, polymer, glass, and ceramic. Microneedles are still evolving as a result of clinical trials and the use of various drugs. The majority of studies that have used this system have yielded positive results. This technique has the potential to be therapeutic in a variety of fields. As a result, it was concluded that these systems offered efficient and superior carriers for transdermal delivery when compared to alternative needle-based formulations.

DECLARATIONS

Author's Contribution

All authors made substantial contributions to the conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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Conflict of Interest

The authors declare no conflict of interest, financial, or otherwise.

Ethical Approvals

Not Applicable

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