REVIEW ARTICLE

Innovations in Topical Drug Delivery: Recent Developments in Transdermal Formulations, Gels, and Patches as Topical Medication Delivery Methods

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Abstract

The article emphasizes new developments in transdermal formulations, gels, and patches as well as breakthroughs in topical medication administration. Transdermal drug delivery has been transformed by emerging technologies such as nanotechnology, 3D printing, and smart materials, which also improve precision and patient-centered care. Customized mixtures made possible by 3D printing provide individualized care, and sensor-equipped smart patches permit continuous observation. These advancements represent a paradigm change in the administration of topical medications, with the potential to enhance therapeutic results, patient adherence, and the efficacy and efficiency of treating a variety of dermatological and systemic disorders.

Key words: 3D printing in topical drug delivary, novel topical formulations, smart patches, hydrogel formulations, microneedle patches

INTRODUCTION

The development of drug delivery systems is a dynamic field in the pharmaceutical sciences that constantly pushes the envelope of innovation to improve therapeutic results and patient experiences. Topical drug delivery methods, such as gels, patches, and transdermal formulations, have attracted a lot of interest among the many modalities because of their potential to provide patient-friendly and non-invasive treatments. These delivery systems have advanced to new levels of complexity in recent years because to a boom in research and development initiatives that aims to solve persistent issues with drug bioavailability, patient adherence, and skin penetration. The incorporation of nanotechnology into topical preparations is one of the notable advances.[1] Liposomes, nanoparticles, and micelles are examples of nanocarriers that have changed the game in terms of improving medication absorption through the skin. These tiny particles not only prevent the medication within from degrading but also enable regulated release, which encourages long-lasting therapeutic benefits. Because of its accuracy, nanotechnology offers new opportunities for customizing medication delivery systems to meet the needs of individual patients, resulting in more effective therapies with fewer adverse effects. Among the revolutionary advancements in transdermal medication administration, microneedle patches are noteworthy.[2] These patches, which provide a less intrusive and painless substitute for conventional injections, use tiny needles to puncture the skin's outer layer and allow medicinal substances to be delivered. Microneedle patches enhance medication absorption in addition to being convenient and patient-friendly, which makes them very promising for the administration of insulin, vaccinations, and other bioactive substances. Significant advancements in hydrogel formulations have demonstrated their promise for topical medication delivery. Because of their special blend of high water content, biocompatibility, and mechanically adjustable qualities, hydrogels are

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excellent choices for medication delivery through the skin. The goals of recent developments in hydrogel technologies are to improve skin adhesion, provide prolonged drug release, and incorporate responsive components that interact with the skin's environment to deliver drugs in a targeted and controlled manner.[3] Customization and accuracy have emerged as crucial themes in the field of 3D printing to advance topical medication administration. Drug release profiles may be customized to meet each patient's demands thanks to the capacity to build formulations that are particular to them. With this technique, one may create drug-loaded matrices and intricate structures with unprecedented control over the dispersion of pharmacological substances in space. Personalized medicine might benefit greatly from the application of 3D printing in topical medication delivery as it continues to advance. Recent developments in materials science and design created renewed interest in transdermal patches, a long-standing participant in medication delivery.[4] Patches with better drug penetration characteristics are the outcome of combining new materials and microfabrication processes. By adding intelligent technologies that react to physiological changes, these patches go beyond traditional medication administration and provide exact control over drug release in response to individual patient demands. As the area develops, transdermal delivery systems—which include peptides and proteins—for biologics—such as these—are becoming increasingly important.[5] In order to overcome the obstacles posed by the skin's natural barrier, scientists are investigating novel strategies to improve these big molecules' transdermal absorption. This has important ramifications for treating a number of illnesses, providing different ways to administer medication and maybe enhancing patient compliance.

In summary, a revolutionary period in pharmaceutical sciences is reflected in the latest developments in topical drug delivery methods. All of these developments—from the use of nanotechnology to the creation of hydrogels, microneedle patches, and 3D printing—combine to show that historical barriers have been surmounted and that topical medication administration can now be more effective. A paradigm change in the way we administer and perceive pharmacological interventions is anticipated as research in this area progresses and more accurate, patient-tailored medications become possible.

"TOPICAL FORMULATIONS" HISTORICAL EVOLUTION

Topical formulations have been used for ages, with civilizations[6] using diverse ingredients for medicinal and cosmetic objectives. Oils and plant extracts, for example, were used as balms and ointments by the Ancient Egyptians. Herbal mixtures were administered topically to heal skin disorders in medieval times. The scientific research of topical medication distribution, on the other hand, began in the nineteenth century, with the advent of pharmaceutical sciences. The introduction of contemporary medications in the 20th century resulted in more uniform formulas. Traditional creams and ointments evolved into complex topical compositions that included scientific concepts as well as technology advances. Understanding of skin physiology advancements, the development of transdermal patches,[7] and current advances in nanotechnology and 3D printing have moved topical drug delivery to the forefront of pharmaceutical research, promising more accurate and patient-friendly therapeutic interventions.

OVERVIEW OF NANOCARRIERS (LIPOSOMES, NANOPARTICLES, MICELLES) IN TOPICAL DELIVERY

Topical medication delivery has been transformed by nanotechnology, which has created novel carriers that improve pharmacological agents' therapeutic effectiveness.[8] Liposomes, nanoparticles, and micelles are examples of nanocarriers that provide special ways to get around the problems with traditional topical formulations. Liposomes are spherical vesicles made of lipid bilayers that are widely used to encapsulate pharmaceuticals that are both lipophilic and hydrophilic. Their adaptable structure enhances bioavailability and minimizes negative effects by enabling customized medication administration. Because of their large surface area and reactivity, nanoparticles—whose sizes range from 1 to 100 nanometers—allow for effective drug loading and regulated release. Their tiny size overcomes the limits of bigger particles by facilitating deep skin penetration.

Amphiphilic molecules produce colloidal formations called micelles, which improve the stability and solubility of medications that are not very soluble in water. Micelles enhance the penetration of drugs through the skin in topical treatments, hence improving therapeutic results. These nanocarriers can extend therapeutic benefits by preventing medication breakdown and enabling sustained release.[9] A paradigm change has occurred with the introduction of nanocarriers in topical formulations, which provide precise control over drug release patterns and target certain skin layers. This review highlights how nanotechnology is revolutionizing medicine delivery and promoting developments that might lead to more potent and individually personalized topical treatments.

MICRONEEDLE PATCHES

A brief overview of microneedle technology

The use of microneedles in medication delivery has revolutionized the field by providing a highly effective and least intrusive method of delivering medicinal substances.

The procedure is almost painless because these tiny needles, which usually have lengths between hundreds of micrometers and a few millimeters, puncture the stratum corneum, the skin's outermost layer, without coming into contact with nerve endings.[10] The development of microneedles has completely changed how drugs are delivered, especially for those that have trouble passing through the skin's protective layer. Although the idea of microneedles was first proposed in the late 20th century, the field of pharmaceutical research has benefited greatly from recent developments in materials science, biomedical engineering, and microfabrication methods. With its arrays of tiny needles, microneedle patches are intended for precise and regulated medication administration. With better patient compliance, less discomfort, and easier self-administration, they provide an alternative to the drawbacks of traditional needle-based injections. Microneedles' adaptability finds uses in diagnostics and vaccine administration, going beyond systemic drug delivery. Microneedles have been acknowledged for their ability to facilitate the distribution of various pharmacological substances such as proteins, peptides, and vaccines, in addition to their therapeutic potential. As microneedle technology develops further, it has the potential to drastically change the healthcare industry by offering a scalable, affordable, and patient-friendly approach to medication delivery.[11] This introduction emphasizes how microneedle technology has the potential to completely change the way drugs are delivered in the future and lays the groundwork for a deeper look at its workings, uses, and most recent developments [Figures 1-4].

Mechanism of action of microneedle technology

The concept behind microneedle patches is straightforward yet clever: they use tiny needles to puncture the stratum corneum, the skin's outermost layer. The procedure is almost painless because these small needles, which are usually between a few hundred and several millimeters in length, create micropores in the epidermis without getting to nerve endings. The two ways that the microneedles work are as follows: First, they improve medication penetration by forming microchannels that let medicinal substances pass through the impenetrable stratum corneum and greatly increase their absorption into the layers of skin under the surface.[7,12] This not only solves issues with low bioavailability and restricted penetration of conventional topical formulations but also makes a wide variety of medicinal substances, including as tiny molecules, proteins, and nucleic acids, easier to distribute. In addition, by inducing a limited, regulated immunological response, the micropores improve the overall effectiveness of vaccines delivered using this method by inducing immune cell activation [Tables 1-4].

Recent investigations and clinical trials using microneedle patches

Microneedle patches have been shown to be versatile and offer the potential for a wide range of therapeutic uses in recent clinical trials and research. Microneedle patches have become a viable alternative to standard injection methods in the field of vaccinations. Prominent studies have investigated their efficacy in immunizing against measles, influenza, and other infectious illnesses. Large-scale immunization programs find the microneedle technique particularly intriguing since it offers faster administration and better patient compliance while proving to be just as immunogenic as conventional injections. Dermatologists are investigating the use of microneedle patches to treat a range of skin conditions. Clinical trials have shown beneficial in treating psoriasis and atopic dermatitis, among other conditions, by demonstrating the feasibility of focused and controlled medication delivery directly to damaged skin areas. By taking use of its ability to create microchannels for better absorption, microneedle patches have also demonstrated promise in the administration of cosmeceuticals and anti-aging medications. Studies are now being conducted on the use of microneedle patches for the administration of medicinal chemicals in dermatology, pain treatment, hormonal contraception, and diabetes control. These studies aim to validate the safety, efficacy, and acceptability of microneedle technology for application in different therapeutic contexts. Taking everything into account, recent findings and clinical trials demonstrate the ground-breaking potential of microneedle patches for a range of therapeutic applications.[13] Given the promising results of ongoing research and the possibility of painless and less intrusive drug administration, microneedle patches have enormous potential for the future of healthcare delivery.

HYDROGEL FORMULATIONS

In the realm of drug delivery, hydrogels—three-dimensional networks of hydrophilic polymers with a high water retention capacity—represent a flexible and exciting platform. They are ideal for the regulated and prolonged release of medicinal substances because to their special qualities. Because hydrogels are hydrophilic, they have an extraordinary ability to hold water, which makes it possible to include a variety of medications into them without compromising their gel-like consistency. Because of their ability to release therapeutic substances under regulated conditions, hydrogels are useful for localized drug delivery applications.[14] The capacity of hydrogels to react to changes in pH, temperature, or ion concentration is one of their most important characteristics. Using this responsiveness, "smart" hydrogels that release medication only when needed can be created, offering a customized and patient-specific method of drug delivery. Because hydrogels are comparable to real tissues and biocompatible, they are also appropriate for use in biomedical applications. Hydrogels that can be tailored to have precise release kinetics can be utilized to administer drugs over extended periods of time.[15] This feature is especially valuable when

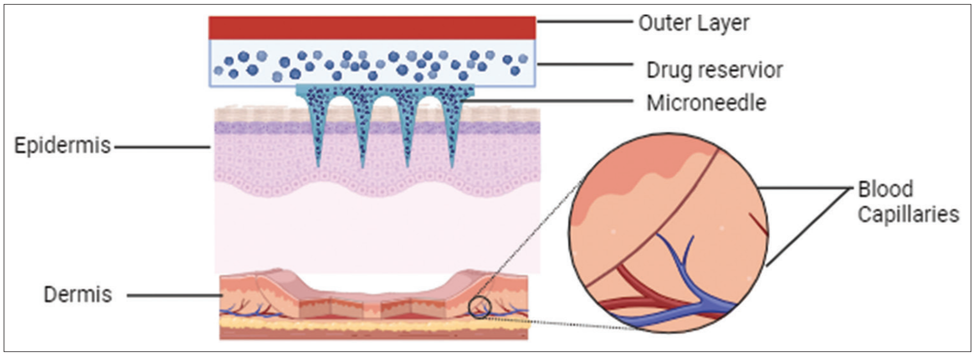

Figure 1: Illustration of microneedle transdermal patch with drug reservior

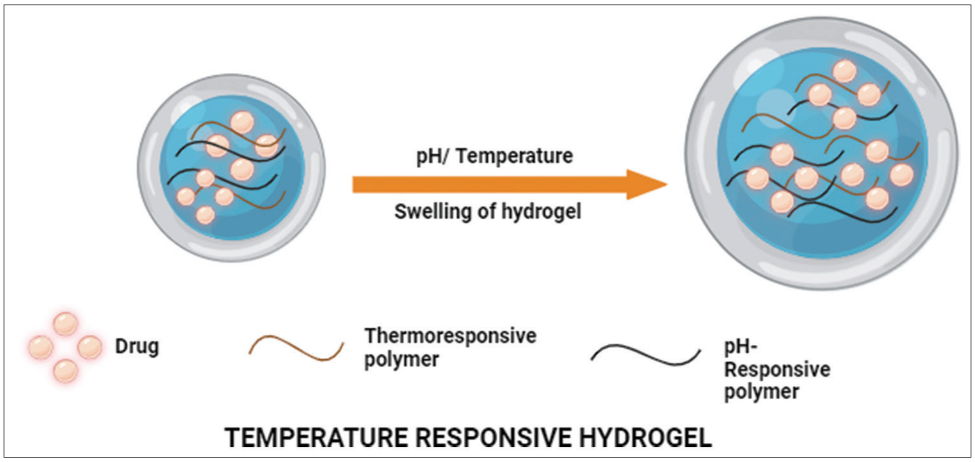

Figure 2: Illustration of temperature-responsive hydrogels

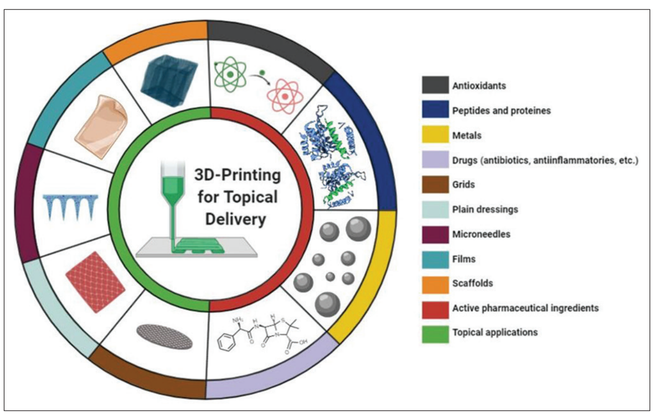

Figure 3: 3D printed products for topical applications

longer treatment results and increased patient compliance are desired. Hydrogel mechanical characteristics can also be altered, allowing the generation of formulations with varying strengths and viscosities that can accept a variety of drug kinds and delivery mechanisms. In conclusion, the characteristics and properties of hydrogels make them versatile and efficient drug delivery methods. Because of their biocompatibility, customizable release kinetics, and environmental responsiveness, hydrogels are an attractive option for creating sophisticated drug delivery systems that provide accuracy and control over the administration of medicinal substances.

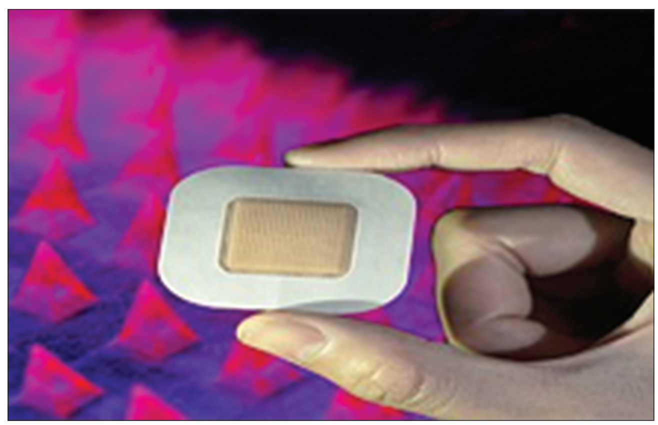

Figure 4: Smart insulin patch

Examples of hydrogel formulations and their performance

Because of its special qualities, which include a high water content, biocompatibility, and mechanical characteristics that can be adjusted, hydrogels are adaptable materials that have found use in a variety of industries. The polyethylene glycol (PEG) hydrogel is a well-known hydrogel composition in the field of biomedical applications. Because PEG hydrogels are highly biocompatible and may contain a variety of therapeutic substances, they have been thoroughly studied for

Table 1: Benefits and uses of nanotechnology for topical medication administration

Sr. No.	Benefits/uses	Description
1	Enhanced Drug Penetration	Liposomes and nanoparticles are examples of nanocarriers that let medications penetrate the skin deeply, overcoming the drawbacks of conventional formulations and enhancing medicinal effectiveness.
2	Improved Bioavailability	Drug solubility and stability are increased via nanotechnology, improving bioavailability and therapeutic results. This is especially important for medications that are not very soluble in water and may not absorb well via the skin.
3	Targeted Drug Delivery	By allowing targeted medicine delivery to specific skin layers or cells, nanocarriers reduce systemic exposure and undesirable consequences. This accuracy has two advantages: it improves therapeutic selectivity and provides tailored therapy.
4	Sustained and Controlled Release	Long-lasting therapeutic effects are made possible by the regulated and sustained medication release provided by liposomes and nanoparticles. Enhancing patient adherence and optimizing dosage schedules are two benefits of this function.
5	Protection of Drug Molecule	The environment that nanocarriers offer to therapeutic molecules protects them against inactivation or destruction. By guaranteeing the stability of pharmacological substances, this protection maintains their effectiveness during the topical administration procedure.
6	Versatility in Formulations	The formulation of several kinds of medications, including hydrophilic and lipophilic chemicals, is made more versatile by nanotechnology. This flexibility accommodates a variety of medicinal substances in topical formulations, enabling a wide range of pharmaceutical uses.
7	Reduced Side Effects	Targeted and controlled drug delivery minimizes systemic exposure, reducing the likelihood of adverse effects associated with traditional formulations. This can enhance the safety profile of topical medications, making them well-tolerated by patients.
8	Customization and Personalization	Because of the adaptability of nanotechnology, topical formulations may be tailored to meet the specific demands of each patient. Because of this customisation, treatment plans may be customized to take into account individual needs, medication sensitivity, and skin type.
9	Integration with Other Technologies	Smart materials and 3D printing are two examples of new technologies that can be easily combined with nanotechnology. The creation of sophisticated, multipurpose topical drug delivery devices with improved therapeutic potential is made possible by this combination.
10	Promising for Dermatological Conditions	Numerous dermatological problems, such as infections, inflammatory disorders, and skin malignancies, may be treated using nanotechnology. Drugs with better penetration and precise distribution provide new ways to treat difficult skin conditions.

use in tissue engineering and drug delivery systems. These hydrogels show promising results for targeted and sustained medication administration due to their regulated drug release patterns. Another notable hydrogel formulation in the realm of wound healing is the chitosan-based hydrogel. Chitosan is responsible for the hydrogel's antibacterial properties. Chitin, a naturally occurring polymer found in crab shells, is used to make chitosan.[16] This characteristic is very beneficial for wound dressings since it promotes tissue regeneration and helps prevent infections. Chitosan hydrogels have been shown to have exceptional wound healing qualities, such as better tissue adhesion and faster healing timeframes. Furthermore, silicone hydrogels are becoming increasingly popular in the context of contact lenses. These hydrogels are distinguished from ordinary hydrogel lenses by their high oxygen permeability, which ensures higher comfort and a lesser risk of corneal hypoxia. Because silicone has been added to the hydrogel matrix, they are more breathable and hence an excellent choice for extended use. In summary, hydrogel formulations exhibit a broad range of uses, and each discipline's particular demands are taken into account while customizing their functioning. PEG hydrogels are great at delivering drugs, chitosan-based hydrogels are great at healing wounds, and silicone hydrogels are better for contact lenses. These illustrations highlight the versatility and usefulness of hydrogels in a range of applications, highlighting their potential for creative solutions in biomedicine and other fields.

Table 2: Recent developments in hydrogel technology for topical applications

Sr. No.	Advancements	Description
1	Nanotechnology Integration	Incorporation of nanocarriers (nanoparticles, liposomes) into hydrogels for enhanced drug loading, controlled release, and improved penetration into the skin.
2	Temperature-Responsive Hydrogels	Development of hydrogels that respond to changes in temperature, allowing for controlled drug release triggered by external factors such as body temperature or environmental conditions.
3	Smart Hydrogels with pH Responsiveness	pH-sensitive hydrogels designed to release drugs in response to variations in pH levels, making them suitable for targeted delivery in specific skin environments.
4	3D-Printed Hydrogel Structures	Application of 3D printing technology to create customized hydrogel structures with precise drug distribution, offering personalized treatment options for topical applications.
5	Hydrogel-Based Microneedle Patches	Integration of hydrogel materials in microneedle patches for transdermal drug delivery, combining the advantages of microneedles with the controlled release properties of hydrogels.
6	Dual-Drug Loaded Hydrogels	Formulation of hydrogels capable of encapsulating and delivering multiple drugs simultaneously, addressing complex treatment regimens or targeting multiple pathways in skin-related conditions.
7	Electroresponsive Hydrogels	Development of hydrogels responsive to electrical stimuli, allowing for on-demand drug release through the application of a controlled electrical field. This feature enhances the precision of drug delivery in topical applications.
8	Biodegradable Hydrogels	Advancements in the design of biodegradable hydrogels, ensuring that the gel matrix gradually degrades over time, improving patient comfort and minimizing the need for removal after application.
9	Hydrogel-Based Wound Dressings	Utilization of hydrogel materials in advanced wound dressings, promoting a moist wound environment, preventing infection, and enhancing the healing process by facilitating controlled release of therapeutic agents.
10	Incorporation of Natural Polymers	Integration of natural polymers (e.g., chitosan, alginate) into hydrogel formulations, aiming to enhance biocompatibility, reduce toxicity, and provide sustainable alternatives for topical applications.

Table 3: Exmpls of 3D printing formulations

Sr. No.	Formulation	Active Ingredients	Key Features	Applications
1	Gel-Based Microneedles	Lidocaine, NSAIDs	Microneedle array for controlled release; Enhanced skin penetration	Pain relief, inflammation
2	Polymeric Nanoparticle Cream	Corticosteroids, Antibiotics	Nanoparticle-loaded cream for sustained release; Customizable particle size	Dermatitis, infections
3	Hydrogel Patch	Antifungals, Moisturizers	3D-printed hydrogel patch for localized drug delivery; Tunable mechanical properties	Fungal infections, dry skin
4	Microporous Foam	Vitamin C, Retinoids	Foam structure for improved skin contact; Porous matrix enhances absorption	Anti-aging, skin rejuvenation
5	Liposomal Lotion	Hyaluronic acid, Peptides	Liposomal encapsulation for targeted delivery; Variable liposome size	Moisturization, wound healing
6	Transdermal patch with microreservior	Analgesics, NSAIDs	Microreservoirs for controlled drug release; Printable patch design	chronic pain, inflammation

NSAIDs: Non-steroidal anti-inflammatory drugs

Table 4: Examples of patches responding to physiological changes

Sr. No.	Physiological change	Smart patch type	Functionality	Example and applications
1	Glucose Level Fluctuations	CGM Patch	Real-time glucose monitoring; Alerts for hypo/hyperglycemia	Diabetes management
2	Temperature Changes	Thermoregulatory Patch	On-demand cooling or heating; Alerts for fever	Fever management, athletic performance
3	Heart Rate Variability	Cardiac Monitoring Patch	Continuous heart rate monitoring; Alerts for irregularities	Cardiovascular health monitoring, stress management
4	Drug Release in Response to Biomarkers	Smart Drug Delivery Patch	Responsive drug release triggered by specific biomarkers	Cancer therapy, pain management
5	Sweat Composition Analysis	Sweat-sensing Patch	Continuous sweat analysis for electrolyte balance; Alerts for dehydration	Sports performance, hydration monitoring
6	UV Radiation Exposure	UV Monitoring Patch	UV radiation sensing; Alerts for excessive sun exposure	Sun protection, skin health
7	Respiratory Rate Changes	Respiratory Monitoring Patch	Continuous respiratory rate monitoring; Alerts for abnormalities	Asthma management, respiratory health
8	Electrolyte Imbalance Detection	Electrolyte Monitoring Patch	Real-time electrolyte level monitoring; Alerts for imbalances	Endurance sports, hydration tracking

CGM: Continuous glucose monitoring, UV: Ultraviolet

3D PRINTING FOR TOPICAL REMEDIES

3D printing principles for the pharmaceutical industry

The concepts of 3D printing in pharmaceuticals concentrate on the layer-by-layer production of medicinal items utilizing additive manufacturing techniques. This novel method enables the exact deposition of medicinal ingredients to produce intricate and personalized dosage forms. Creating printable formulations with certain rheological characteristics is one important idea to follow in order to make sure the materials are appropriate for 3D printing. A key component of 3D printing is personalized medicine,[17] which allows for the creation of customized dose forms to match the needs of each patient individually while taking into consideration things like special medication requirements or allergies. Another important element is controlling drug release profiles, which may be accomplished by carefully planning the geometry and content of each layer. The selection of materials is crucial; polymers, excipients, and therapeutic ingredients that satisfy regulatory criteria for pharmaceutical usage as well as printing requirements are carefully considered.[18] In order to solve regulatory and consistency problems and ensure the repeatability and dependability of 3D-printed medications, quality control and validation procedures are put in place. All things considered, the use of 3D printing to the pharmaceutical industry presents hitherto unseen prospects for precision medicine, dosage flexibility, and improvements in drug delivery systems.

Customization and precision in topical drug delivery through 3D printing

The use of 3D printing in topical medicine administration ushers in a new era of customization and accuracy. This novel technique enables the development of individualized and precisely prepared topical treatments adapted to particular patient requirements. One of the most significant advantages is the capacity to design and print complicated structures that can improve medication administration to specific skin layers or targeted locations. In order to satisfy a wide range of patient needs, the customization function allows different amounts of active pharmaceutical ingredients to be included into a single topical formulation. With 3D printing, precision in topical medicine delivery is made possible by the capacity to regulate the form and content of each layer. This makes it possible to create formulations with regulated release kinetics, guaranteeing either quick release for instant therapeutic benefits or continuous drug release over time. In addition, the technique makes it possible to combine many medications or therapeutic agents into a single topical solution, improving treatment outcomes through combination therapy. Moreover, sophisticated structures like porous matrices and microneedles may be created using 3D printing, which can enhance the skin's penetration and absorption of medications. These structures may be specifically crafted to facilitate medication absorption through the skin's protective layer, perhaps boosting its bioavailability and therapeutic effectiveness. The customization and accuracy of 3D printing in the application of topical medications affect patient comfort and compliance.[19] Customized formulae can accommodate specific patient preferences, such as allergies or skin sensitivity. Adherence to treatment regimens may be improved by the capacity to modify formulations to meet patient demands. Finally, a paradigm change has been made possible by the integration of 3D printing into topical drug delivery systems, which allows for hitherto unheard-of levels of accuracy and customization. This approach has the potential to totally alter the industry by delivering personalized topical formulations that optimize medicine distribution, enhance treatment outcomes, and increase patient pleasure and compliance. Technology has the ability to alter the future of dermatological and transdermal medicine administration as it improves.

RESPONSIVE AND SMART PATCHES

Introduction to smart patches

Smart patches represent a significant breakthrough in wearable health technology, offering novel approaches to medicine administration, diagnostics, and real-time monitoring.[20] These patches generate smart, skin-adherent devices with a variety of functions by combining the concepts of sensor technology, flexible electronics, and data analytics. The main goal of smart patches is to monitor physiological indicators continuously and non-invasively, which would enable proactive healthcare management and individualized therapies. Smart patches are often made to look like unnoticeable, skin-friendly adhesives, but within are a number of sensors that can monitor and identify a number of vital indications, including temperature, heart rate, and blood sugar levels. These sensors gather data in real-time by integrating smoothly with the body.[21]

CONCLUSION

The future of topical medication administration is significantly affected by recent advancements in the industry, including the incorporation of nanotechnology, 3D printing, and smart materials. Precision medicine is being revolutionized by nanocarriers such as liposomes and nanoparticles, which improve medication encapsulation and tailored release. Customized topical formulations with intricate structures to improve skin penetration and patient-specific therapies are made possible by 3D printing. Sensing-enabled smart materials and gadgets provide adaptive medication release and real-time monitoring, enabling tailored and responsive treatment. All of these developments open up new possibilities for customized, patient-centered, and efficient topical medication delivery systems. Better patient adherence, better treatment results, and the creation of novel formulations that tackle the intricacies of diverse transdermal and dermatological uses are all promising directions for the future.

To sum up, topical medication delivery systems have a lot of potential to completely transform patient care and treatment. The combination of state-of-the-art technologies like 3D printing, nanotechnology, and smart materials not only enables focused and accurate medication delivery but also ushers in a new age of customized treatment. This change gives medical professionals the ability to customize therapy for each patient, which may improve patient outcomes and increase therapeutic efficacy. Customized formulations, real-time therapy monitoring, and optimal medication administration all contribute to a paradigm change in healthcare toward a patient-centered approach. As these innovations continue to advance and find wider adoption, they have the potential to reshape the way dermatological conditions and systemic diseases are managed, offering more effective, efficient, and patient-friendly solutions for the challenges in modern healthcare.

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