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New Strategies for Transdermal Delivery of Active Components from Traditional Chinese Medicine: Research Progress and Prospects of Dissolving Microneedle Technology

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Abstract: ***Traditional Chinese medicine (TCM), guided by the holistic concept and the principle of preventive treatment of disease, has unique advantages in the prevention and treatment of chronic, inflammatory, immune-related, and other complex diseases. However, most active components of TCM suffer from poor water solubility, limited stability, rapid in vivo metabolism, and low bioavailability. Conventional oral, injectable, and topical routes of administration have obvious limitations, which severely restrict the clinical application of TCM active components. Transdermal drug delivery can avoid the hepatic first-pass effect and improve drug utilization efficiency, whereas the stratum corneum barrier of the skin remains the key challenge limiting transdermal absorption of TCM active components. As a novel minimally invasive transdermal delivery technology, dissolving microneedles can overcome the skin barrier through an integrated "pierce–dissolve–release" mode. They offer multiple advantages, including good biocompatibility, residue-free application, minimal invasiveness, painlessness, and controllable drug release, thereby providing an innovative solution for efficient transdermal delivery of TCM active components. This article systematically reviews the types and selection principles of matrix materials for dissolving microneedles, summarizes the technical characteristics of mainstream fabrication methods such as centrifugation molding, vacuum molding, 3D printing, and droplet-born air blowing, and outlines various loading strategies for TCM active components. Meanwhile, it reviews the current applications of dissolving microneedles for TCM delivery in skin diseases, autoimmune diseases, pain-related disorders, hair disorders, and medical aesthetic repair. Furthermore, this article analyzes current bottlenecks of this technology, including limited drug loading capacity, insufficient mechanical strength, lack of standardized evaluation systems, and inadequate evidence for clinical translation, aiming to provide theoretical references and technical insights for structural optimization, process improvement, industrialization, and clinical translational application of dissolving microneedle formulations containing TCM active components.***

Keywords: Active components of traditional Chinese medicine, Dissolving microneedles, Transdermal delivery.

1. Introduction

Guided by a dynamic syndrome differentiation system based on the holistic concept and the principle of preventive treatment of disease [1], traditional Chinese medicine (TCM) has demonstrated unique therapeutic advantages in delaying disease progression, improving body functions, and regulating physiological homeostasis. TCM prescriptions are usually composed of multiple medicinal materials, and their diverse active components can exert synergistic effects by simultaneously modulating multiple signaling pathways and molecular targets in the body. Therefore, TCM shows distinctive advantages in the prevention and treatment of complex conditions such as chronic diseases, inflammation-related diseases, immune dysfunction, and pain-related disorders. However, active components of TCM commonly face pharmaceutical challenges, including poor solubility, insufficient chemical stability, rapid in vivo metabolism, and low bioavailability [2]. Oral administration is susceptible to disruption by the gastrointestinal environment, degradation by digestive enzymes, and hepatic first-pass metabolism; injection administration is associated with invasiveness and the risk of infection; and conventional topical formulations are restricted by the skin barrier, making it difficult to achieve effective, stable, and controllable drug delivery [3]. Transdermal drug delivery systems can avoid first-pass metabolism, improve drug bioavailability, and enable sustained drug release. Nevertheless, the stratum corneum, which consists of 10–20 tightly arranged layers of dead corneocytes and lipid bilayers filling the intercellular spaces, is the major barrier limiting the transdermal absorption of exogenous substances [4]. Most active components of TCM have relatively large molecular weights or excessive hydrophilicity, making it difficult for them to effectively penetrate the intact stratum corneum barrier through passive diffusion [5]. Microneedle technology provides an innovative strategy for overcoming the challenges of transdermal drug delivery. Microneedles can create micron-scale channels on the skin surface and deliver drugs into the epidermis or superficial dermis, thereby improving transdermal permeation efficiency while reducing pain and tissue damage [6]. Dissolving microneedles have become a research hotspot because of their advantages, including simple fabrication, absence of sharp residues, good biocompatibility, and stable drug loading. This technology uses water-soluble polymers such as hyaluronic acid and chitosan as drug-loaded matrices and achieves controllable drug release through an integrated "pierce–dissolve–release" mode. Based on this, this article reviews the research progress of dissolving microneedles (DMNs) in the transdermal delivery of active components of TCM, aiming to provide references for the design optimization and translational application of dissolving microneedle formulations containing TCM active components.

2. Matrix Materials for Dissolving Microneedles

2.1 Natural Polymer Materials

Natural polymer materials have become ideal candidates for dissolving microneedles owing to their excellent biocompatibility and biodegradability [7]. Hyaluronic acid (HA) is one of the most commonly used natural materials. As a glycosaminoglycan widely distributed in living organisms, HA can improve skin nutritional metabolism, enhance skin softness and smoothness, and delay skin aging. It also serves as an effective transdermal absorption enhancer [8]. Studies have shown that low-molecular-weight HA (30–50 kDa) exhibits a 12.5-fold higher penetration capacity in ex vivo human skin than highly branched HA [9].

Chitosan is the only alkaline polysaccharide among natural polysaccharides and exhibits good biodegradability and antibacterial properties. When combined with hydrogel matrices, it can enhance the antibacterial capacity of microneedles [10]. The molecular structure of chitosan contains abundant amino and hydroxyl groups, enabling it to interact with both hydrophilic and lipophilic active components of traditional Chinese medicine through intermolecular ionic interactions. Silk fibroin, derived from silk, possesses excellent mechanical properties and biocompatibility; however, its preparation process is relatively complex, and its current application remains limited.

2.2 Synthetic Polymer Materials

Synthetic polymer materials also occupy an important position in the preparation of dissolving microneedles. Polyvinylpyrrolidone (PVP K30) is a non-toxic polymer material with good biocompatibility. After adding hyaluronic acid, it can maintain its biological activity and improve the mechanical strength of microneedles [11]. PVP/VA blends can further optimize the dissolution rate and release characteristics of microneedles to meet the delivery needs of different drugs [12].

Poly (lactic-co-glycolic acid) (PLGA) is a biodegradable synthetic polymer, and its degradation products in vivo are lactic acid and glycolic acid, both of which can be metabolized and eliminated by the body. PLGA-coated doxorubicin nanomicroneedles have been successfully applied in tumor therapy. In addition, polyvinyl alcohol (PVA), as a film-forming agent, is non-toxic and has no side effects, with good biocompatibility and high safety for the human body. It is often used in the preparation of microneedle backing layers [13]. Sodium carboxymethyl cellulose is also a good drug carrier, which can prevent wound infection, and its biological performance is better than that of gauze dressings [14].

2.3 Principles for Material Selection

The material selection of dissolving microneedles should follow the following principles. First, biocompatibility and safety are the primary considerations, and the materials should be non-toxic, non-sensitizing, and completely degradable. Second, the dissolution rate should match drug release; too rapid dissolution may lead to instantaneous drug release, whereas too slow dissolution may affect the therapeutic effect. Third, mechanical strength and puncture ability should be balanced to ensure that the microneedles can pierce the stratum corneum without breaking. Common matrix polymers used for preparing DMNs include HA, PVA, PVP, proteins, and some carbohydrates. The brittleness, solubility, and biocompatibility of different matrix polymers are essential to the mechanical properties, drug loading capacity, and solubility of DMNs. It is worth noting that, to improve the mechanical strength of DMNs and reduce the influence on drug activity and stability, scientists often use two or more polymers in combination or add excipients to polymers as preparation matrices. For example, the combined use of biodegradable or water-soluble polymers such as chondroitin sulfate, polyvinyl alcohol, PVP, trehalose, chitosan, and hyaluronic acid can meet the requirements of both drug loading capacity and mechanical strength [15-17].

3. Preparation Processes of Dissolving Microneedles

The preparation process of microneedles has an important influence on their drug delivery performance and clinical application effect. Preparation parameters not only determine the structural integrity and mechanical properties of microneedles, but also affect the needle morphology, pore structure, and drug distribution in the matrix, thereby regulating drug penetration efficiency and release behavior.

3.1 Centrifugal Mold-Filling Method

The centrifugal mold-filling method is one of the commonly used molding techniques for the preparation of DMNs. Its principle is to use axial centrifugal force to drive the polymer matrix solution into the microcavities of the mold and remove bubbles in the solution, thereby forming microneedle arrays with dense structure and uniform size. The process includes the following steps: first, the mixed drug and polymer material solution is injected into the female mold; second, bubbles in the solution are removed by vacuum degassing to avoid internal defects in the microneedles; then, curing is carried out by natural drying at room temperature or drying in a low-temperature oven; finally, a complete microneedle array is obtained by demolding [18]. Existing studies have confirmed that microneedles prepared by centrifugal casting can form microneedle arrays with regular and uniform morphology and excellent mechanical properties. Hu Qingyue et al. [19] prepared dissolving microneedles loaded with lyophilized aqueous extract powder of Diaphragma Juglandis Fructus using this molding process. The prepared microneedles were neatly arranged with intact needle structures, could successfully penetrate the stratum corneum, and significantly improved the transdermal penetration rate of active components. Xia Aixiao et al. [20] also used the centrifugal molding process to prepare composite dissolving microneedles DMNs-NT. The microneedle tip matrix was prepared by blending chondroitin sulfate (CS) and polyvinylpyrrolidone (PVP), and sodium carboxymethyl cellulose (CMC) was used as the backing substrate. The finished microneedles had a standard quadrangular pyramid structure, with a flat and smooth surface, small size deviation

among needles, stable overall structure, good mechanical puncture strength, and outstanding transdermal delivery effect.

3.2 Vacuum Mold-Filling Method

The vacuum mold-filling method is a mature preparation process for dissolving microneedles (DMNs). It relies on negative pressure to drive the matrix solution to fill the microcavities of the mold, thereby improving the density and integrity of the needle body [21]. The process is divided into three steps: ① preparing the matrix solution according to drug-loading requirements and injecting it into a PDMS silicone rubber mold; ② standing under vacuum negative pressure to allow the solution to completely fill the microcavities; ③ curing and demolding to obtain a complete microneedle array [22-23]. Vacuum can eliminate bubbles, reduce cavities, and improve molding uniformity. This process is simple to operate, has good repeatability, and is suitable for various drugs and polymer matrices [24]. Related studies have confirmed that vacuum-molded microneedles have excellent mechanical and transdermal properties. Xu Yingying et al. [25] prepared microneedles DMNs-NT loaded with Chinese cobra neurotoxin, which showed good puncture strength and significantly improved transdermal drug delivery efficiency. Liao Langkun et al. [26] prepared microneedles loaded with indomethacin hydroxypropyl-β-cyclodextrin inclusion complex, and their in vitro transdermal rate and percutaneous drug amount per unit area were superior to those of the raw drug solution. However, this process has obvious defects: during the drying and curing stage, the drug easily diffuses into the backing layer, resulting in decreased drug loading in the needle tip and weakened delivery effect. Drug enrichment in the needle tip can be achieved by regulating drying parameters, changing matrix viscosity, and using layered casting molding.

3.3 3D Printing Method

3D printing is a high-precision additive manufacturing technology that can directly fabricate microneedles or PDMS molds, flexibly design complex needle structures, and accurately regulate drug distribution [27]. The process involves three-dimensional modeling and printing of the positive mold, casting to prepare the PDMS negative mold, filling the matrix solution to form the needle body, and preparing the backing layer followed by demolding to obtain microneedles. Yang Yuanke et al. [28] used this method to prepare dexmedetomidine hydrochloride-loaded microneedles. The quadrangular pyramid-shaped needles were complete, the puncture strength met the requirements, and the hydrophilicity and morphological consistency were excellent.

3.4 Droplet-Blown Method

The droplet-blown method uses high-speed drying airflow to stretch droplets and simultaneously dehydrate and solidify them to form microneedles. The operation process includes droplet deposition on the substrate, double-layer bonding to stretch the liquid column, lateral airflow drying and solidification, and separation of the substrate to obtain two sets of microneedle arrays at one time. The Kim team [29] used this technology to prepare insulin microneedles. The microneedles had good morphology and mechanical properties, good drug storage stability, and an in vivo hypoglycemic effect close to that of subcutaneous injection.

3.5 Loading Methods for Active Components of Traditional Chinese Medicine

The loading method of active components of traditional Chinese medicine directly affects the drug loading capacity and release characteristics of microneedles. Direct mixing loading refers to mixing drug powder or extracts with polymer solution and then directly casting for molding. This method is simple to operate, but may lead to uneven drug distribution. Co-loading with composite nanoparticles means that the drug is first prepared into nanoparticles and then loaded into microneedles, which can improve drug stability and release controllability [30-31]. Liposome-encapsulated synergistic delivery uses the bilayer structure of liposomes to encapsulate hydrophobic traditional Chinese medicine components and then load them into dissolving microneedles, solving the problem of poor water solubility of some traditional Chinese medicine components [32]. Microemulsions are spontaneously formed by oil, water, and two types of surfactants, with low viscosity, transparent appearance, and thermodynamic stability. They can increase the drug concentration gradient in the skin, loosen the stratum corneum structure to promote transdermal penetration, and intact microemulsion droplets can also penetrate into the skin through the hair follicle pathway. By blending drug-loaded microemulsions with gel matrices, microemulsion gels can be prepared, in which microemulsion particles are uniformly embedded in the gel network. This dosage form can improve drug utilization, enhance stability, and prolong the duration of action, making it a new transdermal drug delivery system with good performance [33].

4. Application of Dissolving Microneedles in the Delivery of Active Components of Traditional Chinese Medicine

Microneedles can construct microchannels in the stratum corneum, greatly improving the transdermal permeation rate and in vivo bioavailability of drugs, thereby achieving efficient and low-risk drug delivery [27]. In recent years, with the continuous development of materials science and formulation processing technology, microneedles, as a new drug delivery carrier, have been gradually applied in the transdermal delivery of active components of traditional Chinese medicine. They have been explored in psoriasis, atopic dermatitis (AD), rheumatoid arthritis (RA), pain relief and other diseases, showing broad clinical application value and industrial transformation prospects.

4.1 Psoriasis

Psoriasis is a recurrent chronic inflammatory skin disease. The thickened stratum corneum in lesions hinders transdermal drug absorption, and long-term systemic medication is often required [34]. Methotrexate, a first-line drug, has poor absorption and obvious systemic side effects when administered orally or by injection [35]. DMNs can open the thickened stratum corneum and improve transdermal drug

delivery efficiency. The combination of polymeric micelles loaded with shikonin and karaya gum microneedles can improve drug water solubility, prolong skin retention, and accelerate transdermal absorption [36]. For psoriatic arthritis, layered microneedles can achieve layered loading and synergistic release of multiple drugs. However, rapid dissolution of microneedles may easily cause drugs to enter the blood, resulting in insufficient local concentration. Current studies mostly combine nanocarriers and responsive materials to achieve precise local controlled release and improve local efficacy and medication safety in psoriasis.

4.2 Atopic Dermatitis

Atopic dermatitis (AD) is a chronic inflammatory skin disease caused by immune dysregulation. Its global prevalence continues to increase, and it is characterized by long-term eczematous lesions and severe pruritus, seriously affecting patients' quality of life. In traditional treatments such as hormones, phototherapy, and systemic immunosuppressive drugs, systemic hormones carry risks of liver and kidney toxicity, while topical preparations are difficult to fully penetrate lesions due to the barrier effect of the stratum corneum. Epigallocatechin gallate (EGCG), with antioxidant and anti-inflammatory activities, can be used as a natural candidate drug for AD, but it is prone to oxidative degradation and has poor stability and bioavailability. Chiu et al. [37] prepared γ-polyglutamic acid microneedles containing ascorbic acid to synergistically stabilize EGCG (EGCG/AA-γ-PGA MNs). The microneedles achieved stable encapsulation and efficient transdermal delivery of the drug. Animal experiments confirmed that once-weekly administration of the microneedles could effectively relieve skin inflammation and epidermal hyperplasia in AD, with better efficacy than daily application of EGCG mixed topical solution. It could also reduce dosing frequency and dosage and improve patient compliance, providing a safe and convenient new drug delivery strategy for long-term management of AD.

4.3 Rheumatoid Arthritis

Rheumatoid arthritis (RA) is a chronic autoimmune disease. Traditional oral or injectable administration has problems such as low bioavailability, obvious systemic toxicity, and poor patient compliance. As a new transdermal drug delivery system, dissolving microneedles provide an innovative solution for RA treatment [38].

Dissolving microneedles construct micron-scale channels in the stratum corneum through a minimally invasive approach and directly deliver drugs to the dermis, achieving a safe delivery process of "puncture–dissolution–zero residue" [39]. The advantages of this technology include: 1) avoiding hepatic first-pass effect and gastrointestinal metabolism, thereby improving drug bioavailability; 2) achieving local targeted delivery and reducing systemic adverse reactions; 3) causing no pain or only slight pain, significantly improving patient compliance; 4) avoiding secondary hazards from needles, with higher safety than injection. Clinical studies showed that Chen Huanhuan et al. [40] prepared microneedles co-loaded with triptolide and celastrol, achieving anti-inflammatory and joint-protective effects through drug synergy. Guo et al. [41] loaded aconitine lipid nanoparticles into cross-linked PVP microneedles, improving drug stability and transdermal efficiency and inhibiting inflammatory development. In addition, drugs such as resveratrol and triptolide also showed good anti-inflammatory effects after delivery by DMNs [38-39]. In the future, preparation processes should be further optimized to improve drug loading and bioavailability and promote clinical translation.

4.4 Pain Relief

Pain management is one of the important challenges in clinical treatment. Traditional oral or injectable administration has problems such as low bioavailability, obvious systemic toxicity, and poor patient compliance. Dissolving microneedles can significantly improve drug transdermal permeation efficiency through a minimally invasive method. At 60 min after administration, the pain threshold of the microneedle group was more than three times that of the traditional transdermal cream group, and the onset time was shortened to 15 min [28]. Active components of traditional Chinese medicine have shown good analgesic potential after delivery by dissolving microneedles. Hyaluronic acid microneedles loaded with neurotoxin have multiple effects, including analgesia, anti-inflammation, and immunosuppression, providing a new strategy for chronic pain treatment [42]. Hou et al. [43] constructed an HA-based microneedle system, HAMNs-CIO@NCs. Cinnamon oil was emulsified with soybean phospholipid to prepare sodium alginate nanocapsules, which were then reinforced by gelatin adsorption and loaded into hyaluronic acid microneedles. This system significantly improved the transdermal ability of cinnamon oil and its analgesic effect on dysmenorrhea. Overall, microneedles used for pain management can improve drug bioavailability, reduce systemic toxic side effects, improve the medication experience of patients, and show prominent industrial transformation potential.

4.5 Androgenetic Alopecia

Androgenetic alopecia (AGA) and alopecia areata are common chronic hair diseases in clinical practice. Conventional treatments include topical minoxidil and oral finasteride. However, topical drugs are difficult to penetrate the stratum corneum and reach hair follicles, while oral administration may cause systemic toxic side effects. Microneedle puncture forms skin microchannels to improve drug delivery efficiency to hair follicles. Meanwhile, minimally invasive stimulation of hair follicle-related cells can promote the secretion of endogenous growth factors and improve local circulation, thereby repairing hair follicles through multiple mechanisms. He et al. [44] constructed a microneedle system based on cyclodextrin metal-organic frameworks co-loaded with minoxidil and cedrol. After cross-linking modification, the carrier showed improved stability and drug loading capacity, promoted dermal papilla cell proliferation, and increased drug accumulation in hair follicles, achieving hair growth effects while reducing systemic drug exposure.

4.6 Hypertrophic Scars

Hypertrophic scars are characterized by abnormal excessive

collagen deposition. Conventional treatments such as pressure therapy, laser therapy, and surgery have limited efficacy, and long-term intervention may easily cause adverse reactions such as pigmentation and tissue damage. At the same time, the double barrier formed by the stratum corneum and dense scar tissue greatly weakens the penetration ability of topical drugs. Ning et al. [45] prepared hyaluronic acid-based microneedles SKN-HA DMNs by a two-step centrifugation method. The microneedles were used as carriers to deliver the active component shikonin (SKN) from traditional Chinese medicine. After puncturing the skin barrier, the drug was precisely delivered to scar lesions. Compared with free drug solution, this system had stronger targeting ability and could reduce non-specific stimulation of healthy skin. It improved anti-fibrotic efficacy while reducing medication risk, providing a safe and efficient transdermal strategy for traditional Chinese medicine in the repair of hypertrophic scars.

4.7 Bronchial Asthma

Bronchial asthma is a heterogeneous disease characterized by chronic airway inflammation. Oral and injectable antiasthmatic drugs may easily damage the gastrointestinal tract, liver, and kidneys. Ordinary transdermal patches are limited by the stratum corneum, resulting in poor drug penetration efficiency and bioavailability, making it difficult to achieve an ideal antiasthmatic effect through acupoint administration. Shi Jianan et al. [46] prepared microneedles ST-DMNs using chondroitin sulfate, PVP K30, and 15% polyvinyl alcohol. The microneedles were loaded with sinapine thiocyanate (ST), an active component of Semen Sinapis, for acupoint application. They opened the skin barrier and achieved efficient transdermal delivery of the active component, providing a new idea for traditional Chinese medicine intervention in respiratory diseases.

4.8 Medical Aesthetics

In recent years, microneedle technology has developed rapidly in the field of skin aesthetics. Traditional topical skincare products remain only on the skin surface, and active components are difficult to penetrate into the dermis. Injectable medical aesthetics may easily cause irritation reactions such as redness, swelling, and pain. Microneedle puncture of the stratum corneum can deliver functional components directly into the deep dermis to improve local effects. At the same time, minimally invasive stimulation of fibroblasts can promote the synthesis of collagen and elastin, exerting anti-aging and anti-wrinkle effects and improving skin hydration and elasticity. This technology is suitable for various skin problems, such as melasma, stretch marks, and dark circles. Compared with traditional cosmetics, microneedles can reduce epidermal retention of active components, avoid nerve-ending stimulation, and show higher safety. Wu et al. [47] prepared Bletilla striata polysaccharide-based cosmetic microneedles, BSP-MNs-QUE@HSF/CDF. Cross-linked cyclodextrin metal-organic frameworks were used to encapsulate quercetin and were coated with human fibroblast cell membranes, effectively improving the water solubility and transdermal efficiency of quercetin. This system showed good application prospects in whitening, anti-aging, and various skin problems.

5. Conclusion

Efficient delivery of active components of traditional Chinese medicine is a key problem restricting the modernization, formulation innovation, and clinical application of traditional Chinese medicine. The inherent defects of traditional drug delivery systems greatly limit the pharmacological advantages and therapeutic value of active components of traditional Chinese medicine. Based on the excellent physicochemical properties of natural and synthetic polymer matrices, dissolving microneedles break through the limitation of the stratum corneum barrier in traditional transdermal drug delivery. With significant advantages such as minimal invasiveness, safety, controllable drug release, good biocompatibility, and no sharp residues, they effectively solve the problems of low transdermal efficiency, insufficient bioavailability, and large systemic toxic side effects of active components of traditional Chinese medicine. They are highly suitable for the therapeutic characteristics of traditional Chinese medicine, including multi-component, multi-target, and mild regulation, and show great application potential in chronic disease prevention and treatment, skin repair, pain management, and medical aesthetic care.

At present, the optimized application of composite matrix systems such as hyaluronic acid, chitosan, and polyvinylpyrrolidone, combined with diversified preparation processes and drug modification technologies such as nano-encapsulation and microemulsion loading, has greatly improved the molding quality, drug loading performance, and drug release accuracy of dissolving microneedles, achieving targeted, long-acting, and safe transdermal delivery of active components of traditional Chinese medicine. A large number of basic studies have confirmed that dissolving microneedle preparations containing active components of traditional Chinese medicine can significantly improve the therapeutic effects of various complex diseases, reduce dosing frequency and medication risks, improve patient compliance, and provide a new direction for the development of novel traditional Chinese medicine preparations.

However, the technology of traditional Chinese medicine dissolving microneedles is still at the stage of basic research, and industrialization and clinical transformation still face many challenges. On the one hand, a single matrix material is difficult to meet the multiple requirements of high drug loading, high mechanical strength, and rapid controllable drug release at the same time, and the adaptability of composite matrix systems still needs further optimization. On the other hand, the standardization and scale-up of the preparation process are insufficient, and the uniformity of microneedles in batch production is difficult to guarantee. Meanwhile, a complete quality evaluation system has not yet been established in the industry. Systematic studies on formulation stability, skin safety, and in vivo drug release kinetics are still insufficient, and large-sample clinical efficacy and safety evidence is lacking, which seriously restricts clinical application and industrial promotion.

Future studies may focus on three core directions: composite modification of matrix materials, intelligent optimization of preparation processes, and innovation of drug loading technologies. It is necessary to balance the mechanical

properties and drug loading capacity of microneedles and improve formulation molding stability and large-scale production levels. At the same time, unified quality evaluation standards should be established urgently, in vitro and in vivo evaluation systems should be improved, long-term safety and pharmacological mechanisms should be further studied, and clinical transformation trials should be promoted. With the deep integration of materials science, formulation technology, and traditional Chinese medicine theory, dissolving microneedle technology will further empower the modernization of traditional Chinese medicine preparations and become a core new technology for the transdermal delivery of active components of traditional Chinese medicine, providing broader application prospects for the innovative development of traditional Chinese medicine and clinical precision therapy.

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