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"Enhanced Transdermal Delivery and Efficacy through Combined Microneedle and Serum Applications"

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1. Introduction

Transdermal drug and cosmetic delivery has gained significant attention due to its potential to bypass first-pass metabolism, reduce systemic side effects, and enable localized treatment. However, the outermost layer of the skin, the stratum corneum, presents a formidable barrier to most active compounds, significantly limiting their absorption when applied topically. To address this challenge, microneedle (MN) technology has emerged as a minimally invasive strategy that creates temporary microchannels in the skin, thereby enhancing the delivery of active ingredients into deeper skin layers.

Among various microneedle platforms, dissolving microneedles (DMNs) have shown particular promise for cosmetic and dermatological applications. These structures are fabricated from biocompatible, water-soluble polymers—most notably hyaluronic acid (HA)—that not only dissolve harmlessly in the skin but also contribute to skin hydration and elasticity. DMNs eliminate the need for removal, reduce medical waste, and are well-suited for consumer-friendly cosmetic products.

This study investigates and compares two novel DMN-based delivery systems designed to optimize both efficacy and user convenience in cosmetic skincare:

Cushion-type HA DMNs integrated with a sponge-ring base, which enhances delivery via a combination of microchannel formation and mechanical cushioning. This system demonstrated a 10-fold to 30-fold increase in skin uptake compared to conventional topical application. Clinical evaluations further confirmed significant improvements in skin hydration, pigmentation, wrinkle depth, and elasticity.

A rolling-type microneedle particle system, designed for broader coverage and ease of application. This system enabled a 5-fold increase in serum delivery efficiency and offers practical advantages for at-home users due to its ergonomic design and flexible application across various facial zones.

Together, these systems represent the next generation of aesthetic microneedle platforms, balancing high efficacy with improved usability. The present study aims to evaluate their transdermal delivery performance, analyze corresponding clinical outcomes, and assess their practical viability in consumer skincare applications.

2. Materials and Methods

2.1. Fabrication of DMCS

DMNs were fabricated on a rectangular polystyrene disk with groove structures on every side of the disk in a diagonal position to assist the flow of the serum. First, to increase the hydrogen bond strength between the polymer and disk, hydrophilic plasma treatment was performed using a plasma cleaner (Harrick Plasma, Ithaca, NY, USA). Hyaluronic acid (HA) (average molecular weight 30 kDa, Soliance, Pomacle, France) was dissolved in distilled water to produce 70% (w/v) and 40% (w/v) HA solutions and homogenized using a paste mixer (KMtech, Gyeonggi, Korea). The solution was dispensed on the disk using a dispenser (Musashi Engineering, Tokyo, Japan) to form 72 droplets and left to dry for 2 h. Then, a homogenized 40% HA solution was laminated onto the dried droplets and fabricated into DMNs by centrifugal lithography, exerting a centrifugal force of 320× g for 2 min under vacuum conditions. The fabricated DMNs were visualized to analyze their morphological properties using a bright-field microscope (Leica, Wetzlar, Germany).

2.2. Mechanical Strength Evaluation of DMNs

To ensure that the DMNs had enough mechanical strength for skin penetration, the fracture force of a single DMN was analyzed using a material testing machine (OmniTest 5.0, Mecmesin Ltd., West Sussex, UK). The DMNs with the disk were placed on the test stage, and a metal probe was moved downward at a continuous speed of 2.0 mm per min. After the probe arrived at the tip of the DMN, the magnitudes of the axial force according to the displacement of the probe were detected and expressed as a graph. The peaks in the graphs, which indicate the fracture forces, were recorded.

2.3. In Vitro Skin Insertion Test

DMNs with the disk were inserted into porcine skin (Cronex, Hwaseong, Korea) by applying thumb force for 5 s to evaluate the in vitro skin penetration. After 1 min of application, the disk was removed, and 0.4% trypan blue solution (Sigma-Aldrich, St. Louis, MO, USA) was applied to the insertion site of porcine skin for staining for 30 min. Excess trypan blue was removed, and porcine skin was taped to remove the residual trypan blue solution. Stained skin was analyzed by visualizing the images using a bright-field microscope. In addition, the dissolution rates of the DMNs under serum supply were evaluated based on the change in height of the DMNs. After applying the DMCS, the DMNs group without serum infusion was detached after 1 min. The DMNs group with serum infusion was infused with the serum after 30 s, followed by detachment after 1 min.

3. Results

3.1. Combinational application of serum and microneedle-cushion and its clinical effects.

The combination of hyaluronic acid-based dissolving microneedles with a cushion-type applicator significantly enhanced transdermal serum delivery. As shown in Figure 1a, the microneedle-cushion system facilitated the creation of uniform microchannels while simultaneously delivering serum into the skin. Clinical outcomes after four weeks of application demonstrated marked improvements in multiple skin parameters.

Specifically, Figure 1b indicates a visible reduction in pore size, while Figure 1c presents three-dimensional skin imaging data showing a substantial decrease in wrinkle depth. Figure 1d highlights a notable depigmentation effect, supporting the system’s efficacy in skin tone improvement. Lastly, ultrasonographic imaging (Figure 1e) revealed increased dermal density, suggesting structural skin enhancement and improved collagen remodeling. These

results collectively affirm the clinical utility of the microneedle-cushion system in aesthetic dermatology.

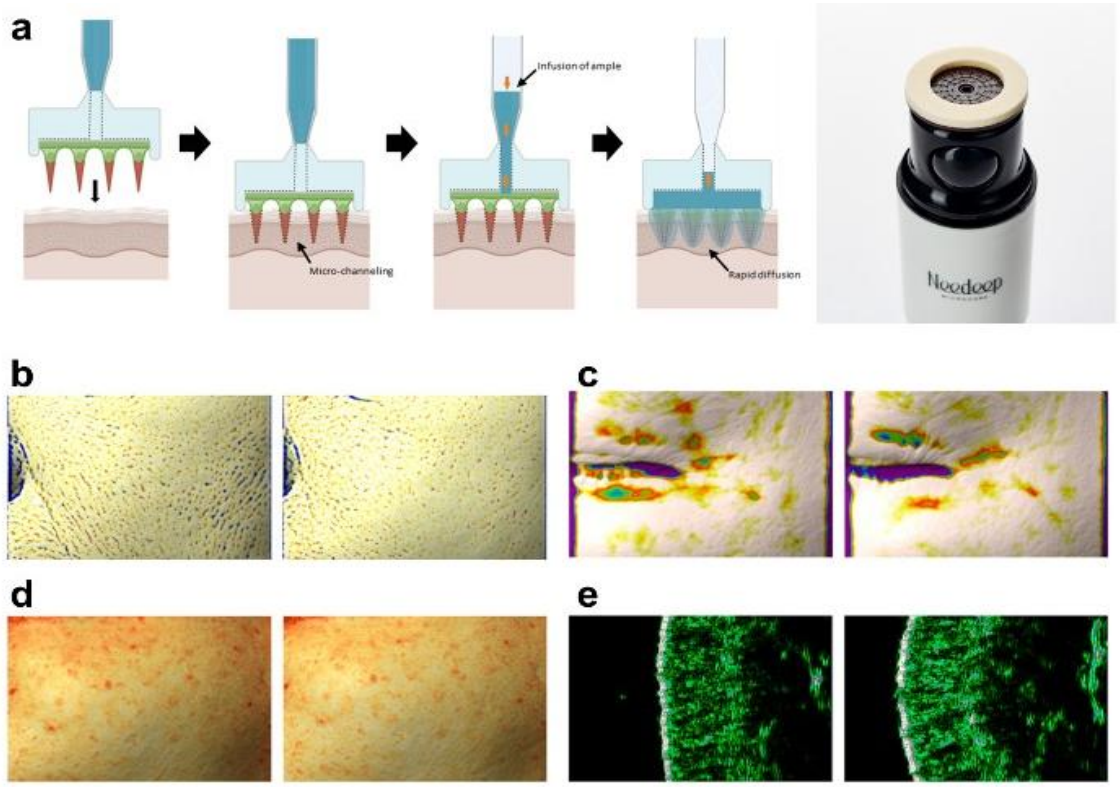

Figure 1. Combinational application of serum and microneedle-cushion and its clinical effects. a) Process of transdermal delivery of microneedle and serum (left) and image of product (right). b) Image of skin pore reduction after 4 weeks. c) Three-dimensional visualized images of skin wrinkles. d) Depigmentation effect after 4 weeks. e) Ultrasonographic images representing dermal density.

3.1. Combinational application of serum and microneedle particle

The hyaluronic acid-based microneedle particle system, Starcle®, was evaluated for its transdermal delivery efficiency in comparison with topical application and conventional solid microneedle rollers (SMR). As illustrated in Figure 2a, Starcle® facilitates enhanced ingredient penetration through dissolvable microneedle particles embedded in a serum-compatible oil matrix (Figure 2b).

Fluorescence imaging analysis revealed that Starcle® achieved significantly deeper and more uniform transdermal delivery compared to both the untreated control and SMR-treated skin (Figure 2c). Cross-sectional imaging (Figure 2d) confirmed that Starcle® penetrated into deeper dermal layers, surpassing the limited diffusion observed with topical application and matching or exceeding the depth achieved by SMR, with more homogeneous distribution. These findings demonstrate the superior delivery potential and application simplicity of the Starcle® system in cosmetic use.

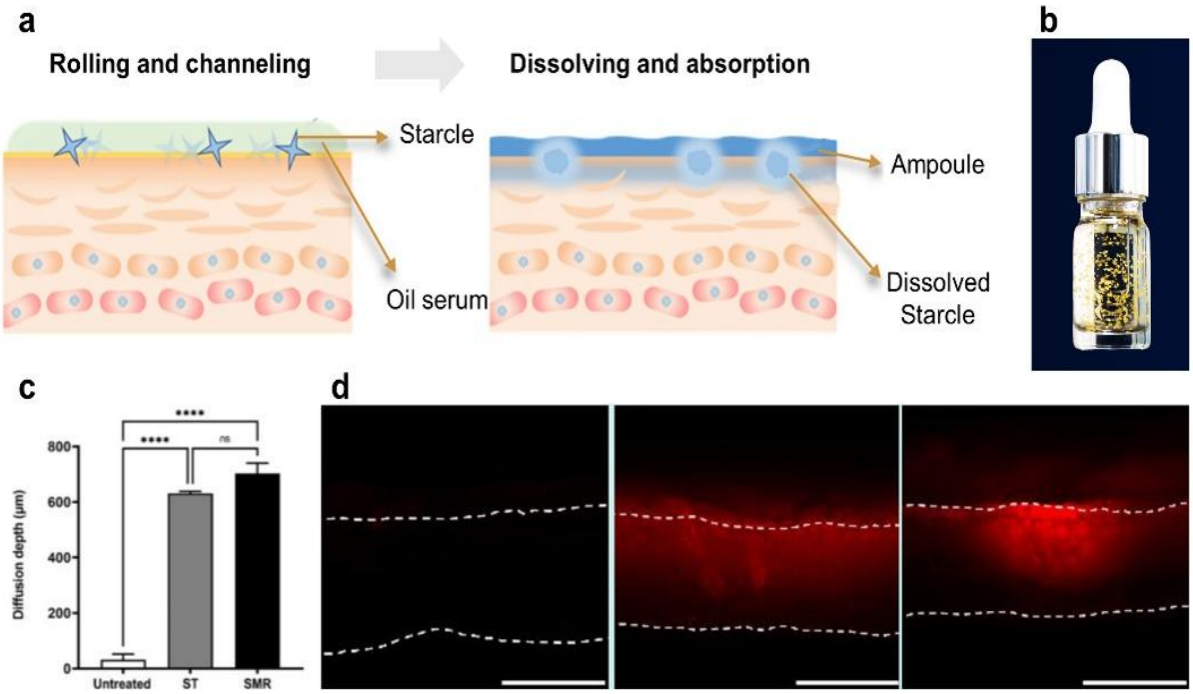

Figure 2. Combinational application of serum and microneedle particle (Starcle®) and its transdermal delivery effect. a) Process of transdermal delivery using hyaluronic acid Starcle. b) Image of Starcle®-oil product. c) Transdermal delivery of Starcle® (ST) compared to topical application (Untreated) and solid microneedle roller (SMR). d) Cross-sectional view of transdermal delivery of topical application (left), Starcle® (middle) and solid microneedle roller (right).

4. Discussion

This study demonstrates the clinical and functional advantages of two hyaluronic acid-based dissolving microneedle systems designed for enhanced transdermal delivery in cosmetic applications. The cushion-integrated microneedle patch not only amplified active ingredient penetration through microchannel formation but also showed significant improvement in key skin parameters such as hydration, pigmentation, wrinkle depth, and elasticity. These outcomes suggest synergistic effects between mechanical stimulation and serum diffusion via the sponge-ring applicator.

Similarly, the rolling-type microneedle particle system, Starcle®, offered a user-friendly alternative with substantial delivery depth and distribution uniformity. Compared to traditional topical application and solid microneedle rollers, Starcle® achieved greater skin penetration while avoiding issues related to device rigidity and invasiveness. The homogenous spread of actives in cross-sectional imaging highlights the system's potential as a next-generation aesthetic delivery platform.

Collectively, these results highlight the role of material design, applicator architecture, and formulation strategy in maximizing both efficacy and usability in cosmetic microneedle technologies.

5. Conclusion

The integration of hyaluronic acid-based dissolving microneedles with customized applicators significantly enhances transdermal delivery and clinical outcomes in aesthetic dermatology. Both the cushion-type microneedle system and the Starcle® particle system

exhibited superior performance compared to conventional methods, providing meaningful improvements in skin condition and ingredient absorption. These findings support the continued development and commercialization of user-friendly, high-efficacy microneedle solutions for the cosmetic market.