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The Laser Speckle Contrast Analysis (LASCA) Technique for Evaluating UV Exposure Effects on Skin: A Dual-layer Spray for Repair

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1. Introduction

The skin, the body ' s largest organ, plays a central role in thermoregulation, sensory perception, and transepidermal water loss (TEWL) prevention. It serves as the primary physical and immunological barrier against environmental insults. The integrity of this barrier is maintained by the coordinated functions of keratinocyte proliferation, tight junction organization, and intercellular lipids within the stratum corneum. The disruption of any of these components may result in increased permeability, dryness, inflammation, and cutaneous sensitivity [1,2].

Among the external aggressors, ultraviolet radiation, particularly ultraviolet B (UVB), is a well-recognized contributor to premature skin aging and epidermal barrier disruption. UVB exposure promotes oxidative stress, DNA photodamage, and inflammatory responses, leading to erythema, pigment alterations, collagen degradation, and the loss of barrier function [3,4]. Erythema, characterized by vasodilation and increased dermal blood perfusion, is a common early-phase response to UVB exposure [5]. However, traditional barrier repair assessments primarily focus on epidermal parameters, such as TEWL and corneocyte hydration, while failing to account for dermal vascular dynamics [6].

Laser speckle contrast analysis (LASCA) is an emerging non-invasive optical imaging method capable of quantifying skin microcirculation in real time. Unlike conventional point-based measurements, LASCA provides spatially resolved perfusion mapping over wide skin areas and offers a reproducible and sensitive assessment of dermal blood flow [7]. Although LASCA has been applied to systemic sclerosis, burns, and wound healing, its applications in photoinduced erythema and UV-related vascular responses remain limited [8,9].

In the present study, we report the first application of LASCA to assess UVB-induced microvascular changes during the post-exposure repair phase. By integrating LASCA with hyperspectral imaging, we comprehensively evaluated both the epidermal and vascular repair responses. This dual-modality approach was used to confirm the efficacy of the novel biphasic facial spray containing citrus peel extract, betaine, panthenol, squalane, sodium hyaluronate, and ceramides. The formulation significantly reduced UV-induced erythema,

accelerated barrier recovery, and promoted vascular normalization, thereby providing objective evidence of its dermocosmetic benefits.

2. Materials and Methods

2.1 Research Product

The test product, referred to as a hydrating and dermo-soothing spray (HDS), is a biphasic facial spray comprising an oil phase and a water phase formulated with citrus peel extract, betaine, panthenol, squalane, sodium hyaluronate, and ceramides. The product was supplied by Proya Cosmetics Co., Ltd.

2.2 Clinical Assessment in UV-Induced Erythema Model

A randomized controlled study was conducted in 31 healthy Chinese volunteers (10 males and 21 females; aged 21–60 years, mean age 34 ± 12 years) to evaluate the short-term soothing and barrier-repairing effects of HDS on UV-induced erythema. The minimum erythema dose (MED) on the upper back was determined for each participant [10]. Two symmetrical areas were irradiated with 2 MED of UVB using Solar® Light (601-300-V2.5, Solar Light, USA), with one site designated as the treatment area (HDS application) and the other as the untreated control. HDS was applied once daily for two consecutive days.

Skin erythema was assessed using the Mexameter® MX18 (Courage & Khazaka, Germany). TEWL was measured with the Tewameter® TM Hex (Courage & Khazaka, Germany), and stratum corneum hydration was determined by the Corneometer® CM825 (Courage & Khazaka, Germany). Skin color (a* value) was assessed with the Colorimeter® CL400 (Courage & Khazaka, Germany), and dermal blood perfusion was monitored using LASCA with the PeriCam PSI system (Perimed, Sweden). All evaluations were conducted under controlled environmental conditions (21 ± 2°C, 50 ± 10% relative humidity [RH]). Erythema severity was recorded visually using standardized photographic documentation. The integration of LASCA with real-time vascular imaging in this model represents a novel approach for quantifying erythema-related microcirculatory responses.

2.3 Clinical Efficacy Evaluation in Sensitive Skin Population

A 4-week clinical study was conducted with 32 Chinese female participants (aged 19–59 years, mean age 27.53 ± 6.98 years), each of whom had previously tested positive in a lactic acid stinging test and was diagnosed with sensitive skin [11]. The biphasic spray was applied to the entire face twice daily (morning and evening) for 28 consecutive days. Skin assessments were performed at three time points: baseline (D0), 15 min after initial application (D0_T15min), day 14 (D14), and day 28 (D28).

Facial redness (a* value) and red area percentage were evaluated using the VISIA-CR® system (Canfield, USA) in combination with Image-Pro Plus software (Media Cybernetics, USA). TEWL was measured using the Tewameter® TM Hex (Courage & Khazaka, Germany), and hydration of the stratum corneum was assessed with the Corneometer® CM825 (Courage & Khazaka, Germany). Subjective stinging sensation was collected through standardized self-report questionnaires. All tests were performed under controlled indoor conditions (21 ± 2°C, 50 ± 10% RH). The combined use of short- and long-term assessments enabled comprehensive evaluation of both immediate soothing and progressive barrier repair efficacy.

2.4 Statistical Analysis

All statistical analyses were performed using SPSS software. Data are expressed as mean ± standard deviation (SD). The Shapiro – Wilk test was used to assess normality. For within-group comparisons, paired t-tests were used for normally distributed data, and

Wilcoxon signed-rank tests were used for non-normal data. Between-group comparisons were performed using independent t-tests or Mann–Whitney U tests. Statistical significance was set at (two-tailed) $p < 0.05$.

3. Results

3.1 Effects of HDS in UV-Induced Erythema Model

In UVB-irradiated areas, the application of biphasic HDS significantly improved multiple skin parameters compared to untreated control sites. At 24 h (T1) and 48 h (T2) post-application, TEWL decreased by 7% and 10%, respectively, relative to baseline (T0), whereas stratum corneum hydration increased by 7% at both time points. The Erythema Index (EI), which indicates erythema severity, was reduced by 7% at T1 and 19% at T2, and the skin redness index (a* value) significantly decreased by 6% and 17%, respectively. Notably, dermal blood perfusion assessed using LASCA showed a marked reduction of 29% at T1 and 45% at T2. These findings indicated that HDS rapidly alleviated UVB-induced erythema and promoted barrier function recovery. Representative images from Participant 4 illustrate visible improvements in both erythema and dermal blood perfusion following HDS treatment.

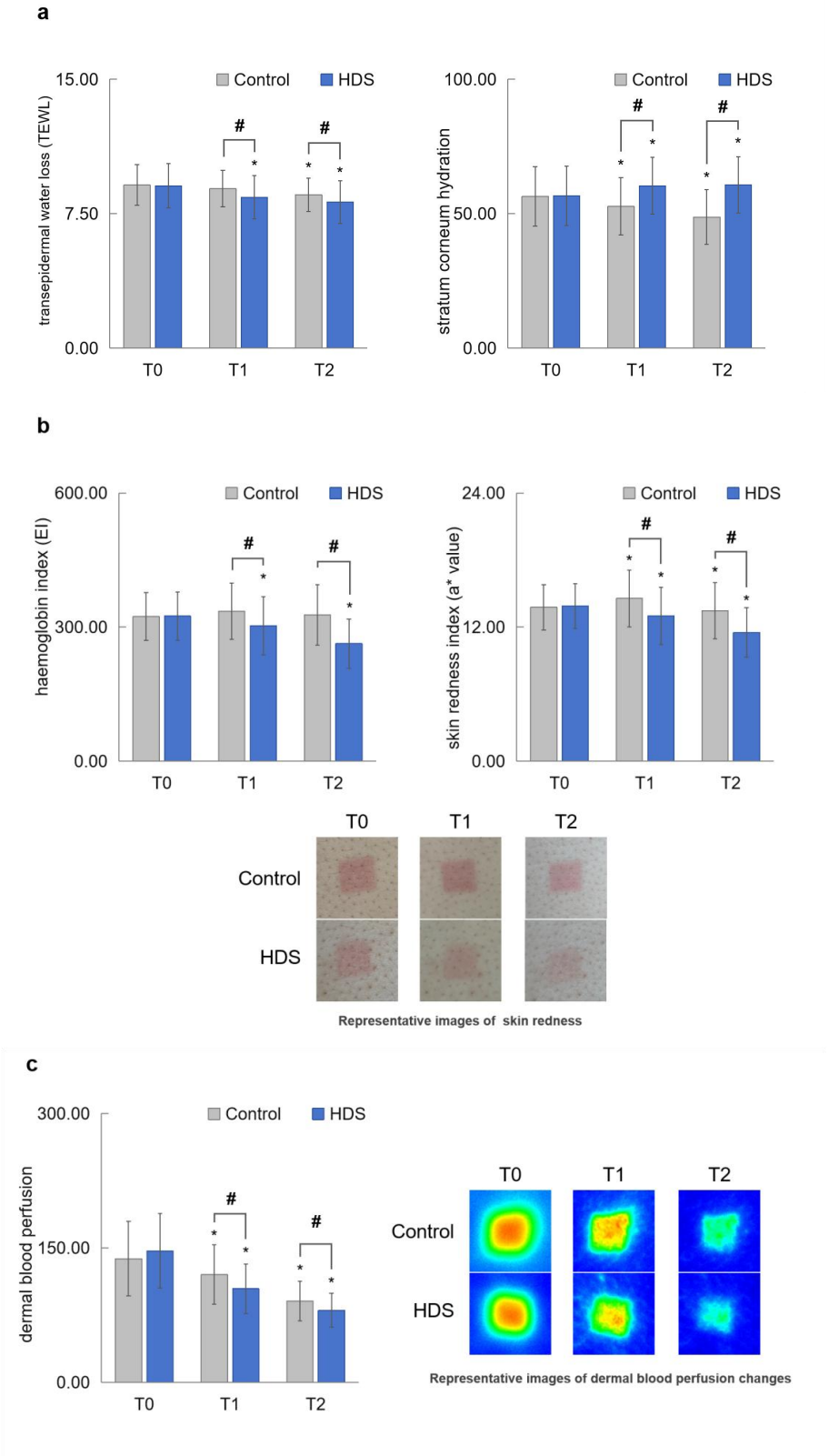

Figure 1. Skin barrier function, erythema severity, and blood perfusion changes following application of HDS in UVB-irradiated skin. Changes in facial redness (a* value) and red area percentage measured using VISIA-CR following HDS use in participants with sensitive skin. Progressive reductions were observed at D0_T15min, D14, and D28 compared to D0. Representative VISIA-CR facial red area images are shown from Participant 25 (HML, female,

age 39), illustrating visible improvement in redness over time. (b) Erythema severity. Both EI and a* value decreased significantly in the HDS group at T1 and T2. Representative clinical images of UVB-induced erythema are shown from Participant 32 (GS, male, age 25), demonstrating a visible reduction in redness over time. (c) Dermal blood perfusion quantified by LASCA. Blood perfusion was significantly reduced after HDS treatment at T1 and T2 compared with both baseline and the control group. Representative LASCA perfusion maps are shown from Participant 5 (LF, female, age 55), illustrating normalization of vascular response. All values are expressed as mean ± SD. Statistical significance was determined using paired t-tests.*, $p < 0.05$ versus T0; #, $p < 0.05$ versus control.

3.2 Effects of HDS in the Sensitive Skin Population

In a 4-week study, HDS significantly improved multiple clinical indicators in participants with sensitive skin. At D0_T15min, facial redness (a* value) and red area percentage decreased by 4% and 19%, respectively, compared to D0. By D14 and D28, the a* values further decreased by 5% and 8%, respectively, whereas the percentage of the red area assessed by VISIA-CR declined by 31% and 40%, respectively.

In parallel, TEWL was reduced by 7% and 10% on D14 and D28, respectively, whereas stratum corneum hydration increased by 36% and 40%, respectively, indicating improved skin barrier function. In addition, participants reported marked relief in subjective skin discomfort, including itching, burning, tightness, and other sensations. The self-assessment radar plot showed progressive symptom alleviation from D0 to D28, reflecting enhanced overall skin comfort and tolerability.

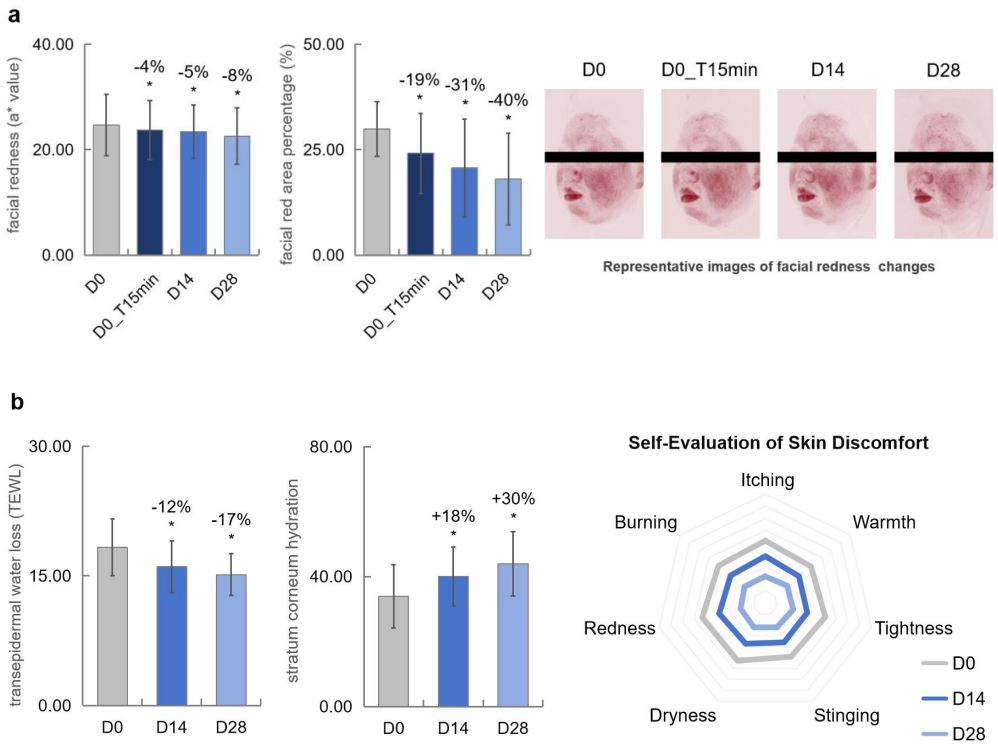

Figure 2. Effects of HDS in the Sensitive Skin Population Over 28 Days. (a) Changes in facial redness (a* value) and red area percentage were measured using VISIA-CR following HDS use in participants with sensitive skin. Progressive reductions were observed at D0_T15min, D14, and D28 compared to D0. (b) Improvement in skin barrier function indicated by decreased TEWL and increased stratum corneum hydration at D14 and D28. Self-evaluation

of skin discomfort including itching, burning, tightness, dryness, stinging, and redness. Radar plots illustrate symptom relief over time, highlighting enhanced skin comfort and tolerability. Scoring scale: 0 to 9, where 0 indicates no discomfort (excellent) and 9 indicates severe discomfort (poor). All values are expressed as mean ± SD. Statistical significance was determined using paired t-tests; *, $p < 0.05$ versus D0.

4. Discussion

This study presents a novel approach that integrates LASCA with hyperspectral imaging to evaluate the efficacy of a biphasic facial spray (HDS) in mitigating UVB-induced skin damage and improving sensitive skin conditions. LASCA allowed for real-time, noninvasive assessment of dermal blood perfusion, providing valuable insights into the microvascular responses associated with erythema and inflammation [12,16].

LASCA has been increasingly recognized for its reproducibility and sensitivity in evaluating skin perfusion, particularly under conditions such as systemic sclerosis and burn wound monitoring [12,16]. In the context of UVB-induced erythema, LASCA facilitated the detection of significant reductions in dermal blood flow following HDS application, representing the most substantial change among all measured parameters, especially in immediate recovery following UV exposure. This highlights the potential of LASCA in evaluating therapeutic interventions aimed at restoring vascular homeostasis [17].

The HDS formulation, enriched with citrus peel extract, betaine, panthenol, squalane, sodium hyaluronate, and ceramides, showed significant improvements in skin hydration and barrier function. Ceramides play critical roles in stratum corneum cohesion, lipid lamellar structure, and skin barrier recovery [19]. Clinical studies have confirmed the effectiveness of ceramide-containing formulations in alleviating the symptoms of sensitive skin and reducing TEWL [11,19].

Furthermore, citrus-derived flavonoids and botanical antioxidants have demonstrated antioxidative and anti-inflammatory properties [15,21], which likely contributed to the improvements in hydration and erythema observed in this study. The synergistic action of the antioxidant and barrier-repairing components of HDS likely underpins its dual action in vascular normalization and epidermal recovery [11,17].

By combining LASCA with traditional epidermal physiological metrics, such as TEWL and stratum corneum hydration, this study achieved a more comprehensive depiction of skin repair. This dual-modality assessment model supports recent trends in dermatological research, emphasizing the multi-layer analysis of skin responses to both environmental damage and topical intervention.

5. Conclusion

In conclusion, the integration of LASCA and hyperspectral imaging enabled multidimensional evaluation of biphasic spray HDS in both UVB-induced erythema and sensitive skin models. These findings suggest that HDS significantly improves skin barrier integrity, reduces visible redness, and restores microvascular perfusion in a rapid and sustained manner.

These results highlight HDS as a promising dermocosmetic candidate for managing acute photodamage and enhancing resilience in sensitive skin types [14,18,19]. Furthermore, the use of LASCA as a noninvasive imaging tool offers a reproducible and physiologically relevant methodology for future cosmetic efficacy trials [12,17].

As skincare science advances toward precision dermatology, incorporating vascular function metrics along with epidermal data will be essential for evaluating holistic product performance. Future studies should investigate the long-term applications of HDS, expand sample diversity

across ethnic groups and skin phototypes, and explore the underlying molecular mechanisms through transcriptomic or proteomic analyses [11,13].

6. References

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