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Pigmentation and Oxidative Biomarker Modulation Across All Skin Types (FST I-VI) Following Exposure to Boundary Region Wavelengths (Longest Ultraviolet A + High Energy Visible Light): A Controlled Clinical Study

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Introduction

- Current UV filters provide protection against hyperpigmentation, photoaging and photocarcinogenesis in the 290–380 nm range beyond which absorbance starts to diminish.

Objectives

- This study assessed the level of pigmentation and quantifiable oxidative stress biomarkers following irradiation by longest ultraviolet A (LUVA) radiation alone or in combination with high energy visible light (HEVL)(LUVA+HEVL).

Method

- Females (N=18, mean age 44 years) were enrolled with a balanced representation of all skin tones (N=3 per each Fitzpatrick skin type [FST]).
- Test areas on the backs of individuals were exposed to 2 different regimens of radiation - LUVA , 380-400nm and LUVA+HEVL, 380-420 nm - Boundary Region Light **(Table 1)**. Clinical pigmentation was graded on a visual grading scale of 0, 0.5, 1, or 2.
- Immediate Pigment Darkening (IPD) at 15 min and Persistent Pigment Darkening (PPD) at 18-22 hours post-exposure were recorded. Cross polarized images were taken of each test site, and Individual typology angle (ITA), L*, and a* were calculated for the subsites. Chromameter measurements were taken at the highest dose subsite within the test site, and ITA was calculated for the subsite.
- Skin was swabbed from each subsite exposed to radiation to evaluate catalase (antioxidant enzyme) activity and malondialdehyde (MDA) (lipid peroxidation marker) concentration using fluorescence assay (IU/mg) and gas chromatography/mass spectrometry (GC/MS; ng/mg protein), respectively.

Table 1. **Dose of Irradiation in J/cm²**

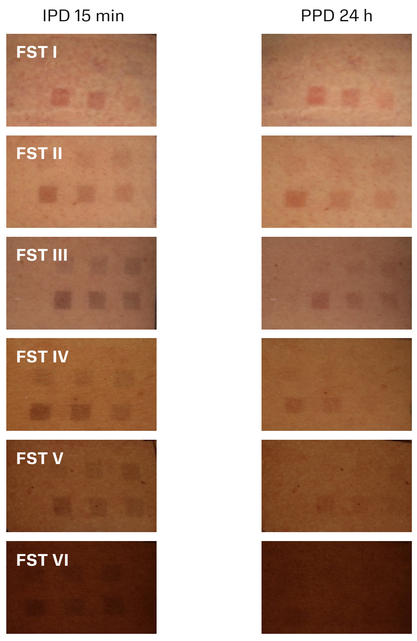
Subsite	Regimen 1 LUVA 380-400 nm[a]	Regimen 2 LUVA+HEVL 380-420 nm[a]
1	1.61	3.21
2	2.25	4.49
3	3.15	6.29
4	4.40	8.81
5	6.17	12.33
6	8.63	17.27
7	12.09	24.17
8	16.92	33.84
9	23.69	47.38
10	33.16	66.33
11	46.43	92.86
12	65.00	130.00

[a]At increasing doses vs unirradiated control.
Each test site also included an unirradiated control (Subsite 0)

Results: Wavelengths Beyond 380 nm Induced Hyperpigmentation in All Participants Regardless of Skin Type

- Boundary Region Light (380-420 nm) induces IPD and PPD in all FSTs **(Figure 1)**

Figure 1. **Representative Images Showing Subsites 7-12**



- Pigmentation was most perceptible in FST IV **(Tables 2 and 3)**

Table 2. **Minimal Immediate Pigment Darkening Dose (MIPDD) and Minimal Persistent Pigment Darkening Dose (MPPDD): the Lowest Dose at which Grade 1 is Achieved at 15 min or 18-22 h Post Exposure; Average of N=3 per FST**

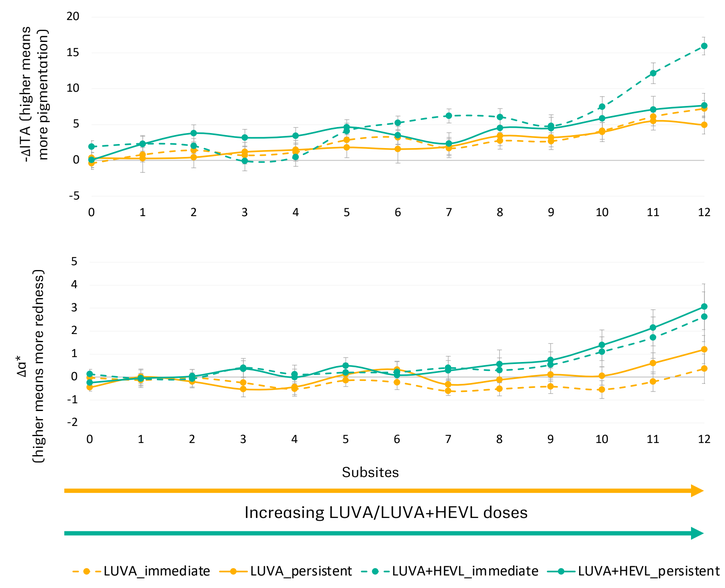
	MIPDD (J/cm²)		MPPDD (J/cm²)	
FST	LUVA	LUVA+HEVL	LUVA	LUVA+HEVL
I	9.57	7.37	18.16	47.38
II	5.58	8.30	22.98	29.17
III	3.27	5.69	25.43	26.79
IV	2.75	3.64	4.99	15.31
V	4.57	11.22	22.38	67.18
VI	5.39	8.32	25.04	43.66

Table 3. **Mean Δa* measured by Chromametry at subsite 12**

	15 min			24 hrs		
	Control	LUVA	LUVA+ HEVL	Control	LUVA	LUVA+ HEVL
Δa*	0.03	0.05	0.75	-0.01	0.55	1.13

- Addition of HEVL induced more pigmentation than LUVA alone **(Figure 2)**

Figure 2. **Changes in Pigmentation with HEVL and LUVA from Imaging Data**

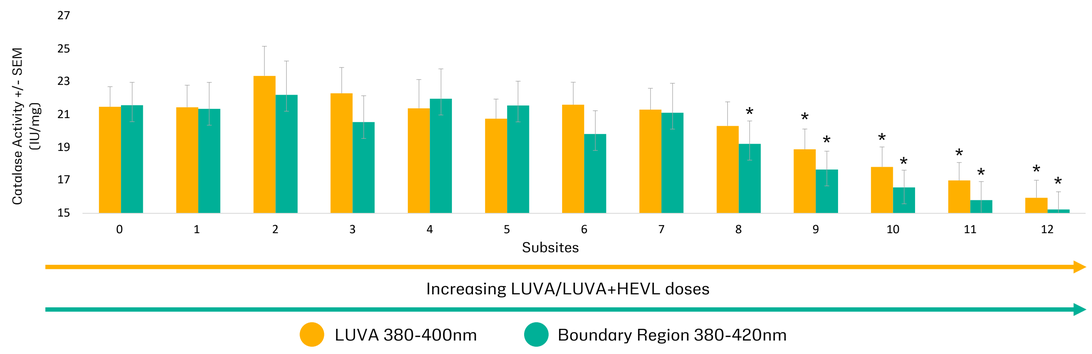


Error bar represents 1 standard error of the mean, N=16

Results: Higher Doses of LUVA and LUVA+HEVL Modulated Oxidative Markers in All Skin Types

- LUVA alone and LUVA+HEVL significantly decreased catalase activity for all skin types compared to unirradiated control, N=18 **(Figure 3)**

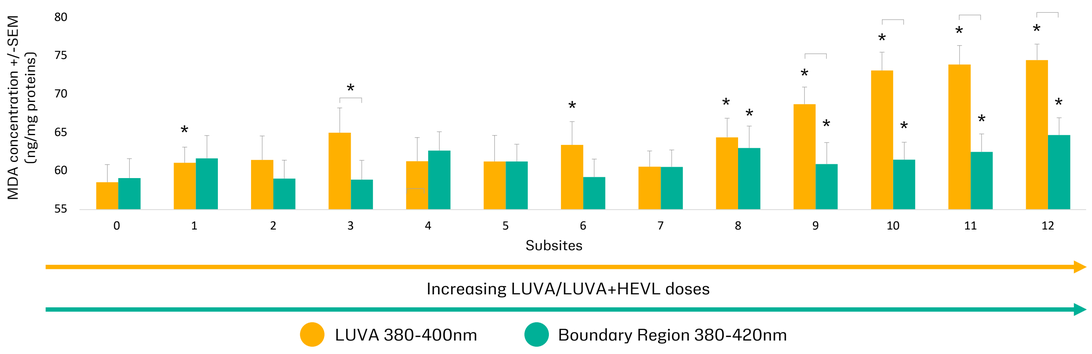
Figure 3. **Changes in Catalase Activity with HEVL and LUVA**



* Indicates significant difference from unirradiated Control; p<0.05

- Both regimens significantly increased MDA concentration compared to unirradiated control, additionally LUVA significantly increased MDA concentration compared to LUVA+HEVL at higher doses, N=18 **(Figure 4)**

Figure 4. **Changes in MDA Concentration with HEVL and LUVA**



* Indicates significant difference from unirradiated Control; p<0.05.
Indicates significant difference LUVA vs LUVA+HEVL; p<0.05.

Table 4. **FST I Showed Significant Change in Biomarker Concentration at the Highest Dose (Subsite 12) Compared with Unirradiated Control (N=3)**

	% Catalase ↓	↑ % MDA
LUVA	31.98±0.22	33.26±0.30
LUVA+HEVL	45.73±0.19	28.30±0.29

Conclusion

- All participants responded to both radiation regimens by developing immediate and persistent skin pigmentation.
- All FSTs had a dose dependent increase in pigmentation (↓ITA) while FST I/II had a dose dependent increase in redness (↑a*).
- IPD at 15 mins and PPD at 18-22 hours were strongest in FST IV requiring the lowest minimum mean energy dose of 3.63 J/cm2 to induce IPD and 15.31 J/cm2 for PPD with Boundary Region Light.
- Mean oxidative stress biomarkers were significantly changed with a decrease in catalase activity and an increase in MDA concentration at higher doses across all skin types (n=18) for both light regimens.
- Most significant changes in biomarkers occurred at the highest doses in the FST I subpopulation (n=3) as compared with the unirradiated control.
- Hyperpigmentation and oxidative stress in all skin types following boundary region light exposure was established.
  - This will enable evaluation of protection beyond the 290–380nm spectrum in future studies.

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European Academy of Dermatology and Venerology (EADV), September 30– October 3, 2026, Vienna, Austria