

Supplementary Information

Wearable near-infrared LED photothermal microneedle patch reduces periorbital wrinkles in a randomized pilot clinical trial

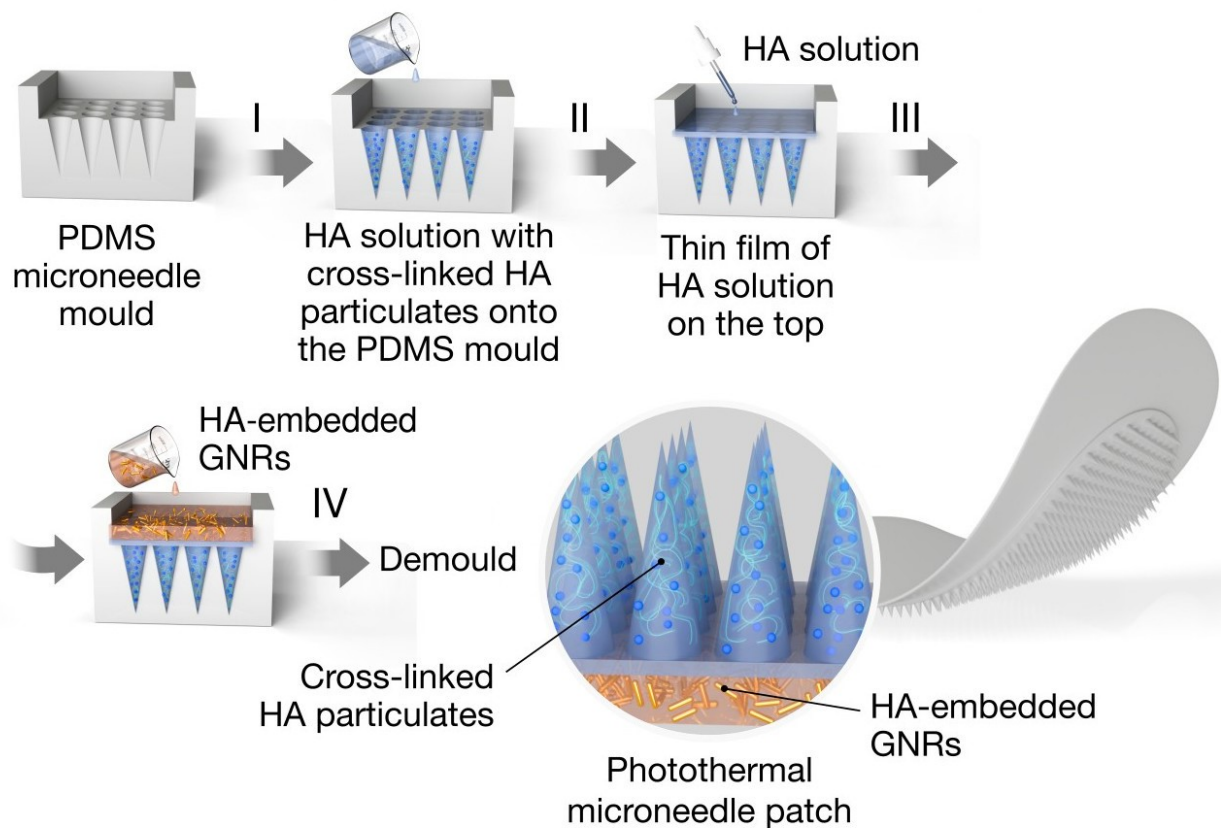


Fig. S1. Fabrication of a photothermal-responsive soluble microneedle eye patch. A PDMS microneedle mould is (I) filled with a hyaluronic-acid (HA) solution containing cross-linked HA particulates to form dissolvable tips, (II–III) overcoated with a thin HA film, and (IV) capped with a hydrocolloid backing loaded with HA-embedded gold nanorods (GNRs), then demoulded. The resulting patch comprises HA microneedle tips with dispersed cross-linked HA particulates on a backing that incorporates HA–GNRs for photothermal activation. Abbreviations: PDMS, polydimethylsiloxane; HA, hyaluronic acid; GNRs, gold nanorods.

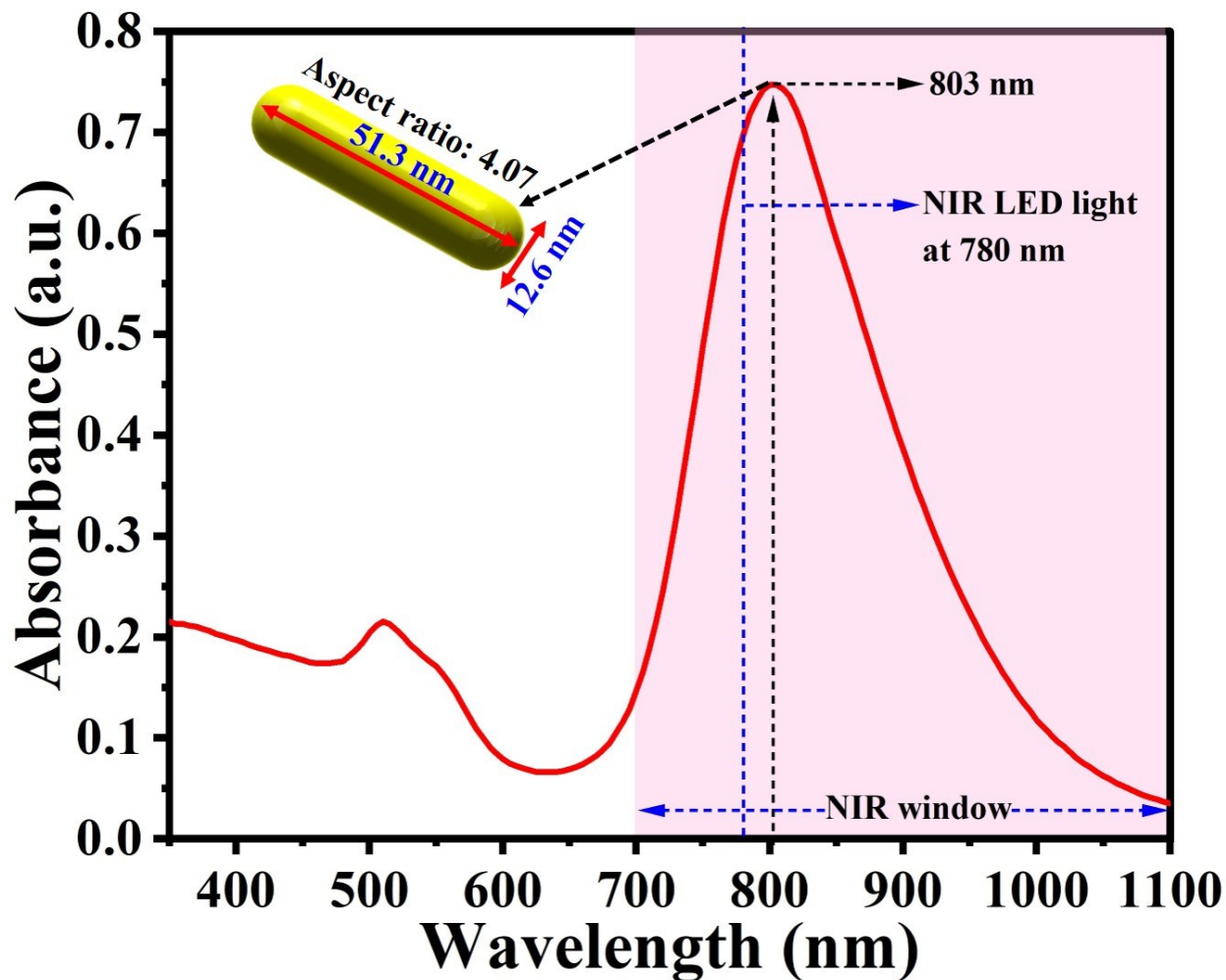


Fig. S2. UV-vis-NIR absorption of gold nanorods and overlap with the excitation source. Spectrum of a GNR dispersion showing a longitudinal LSPR maximum at ~ 803 nm; the shaded band marks the NIR tissue window (≈ 700 – $1,100$ nm). The near-infrared (NIR) LED used in this study (780 nm) lies close to the LSPR peak. Inset, schematic of a representative GNR (length ~ 51.3 nm, diameter ~ 12.6 nm; aspect ratio ~ 4.1).

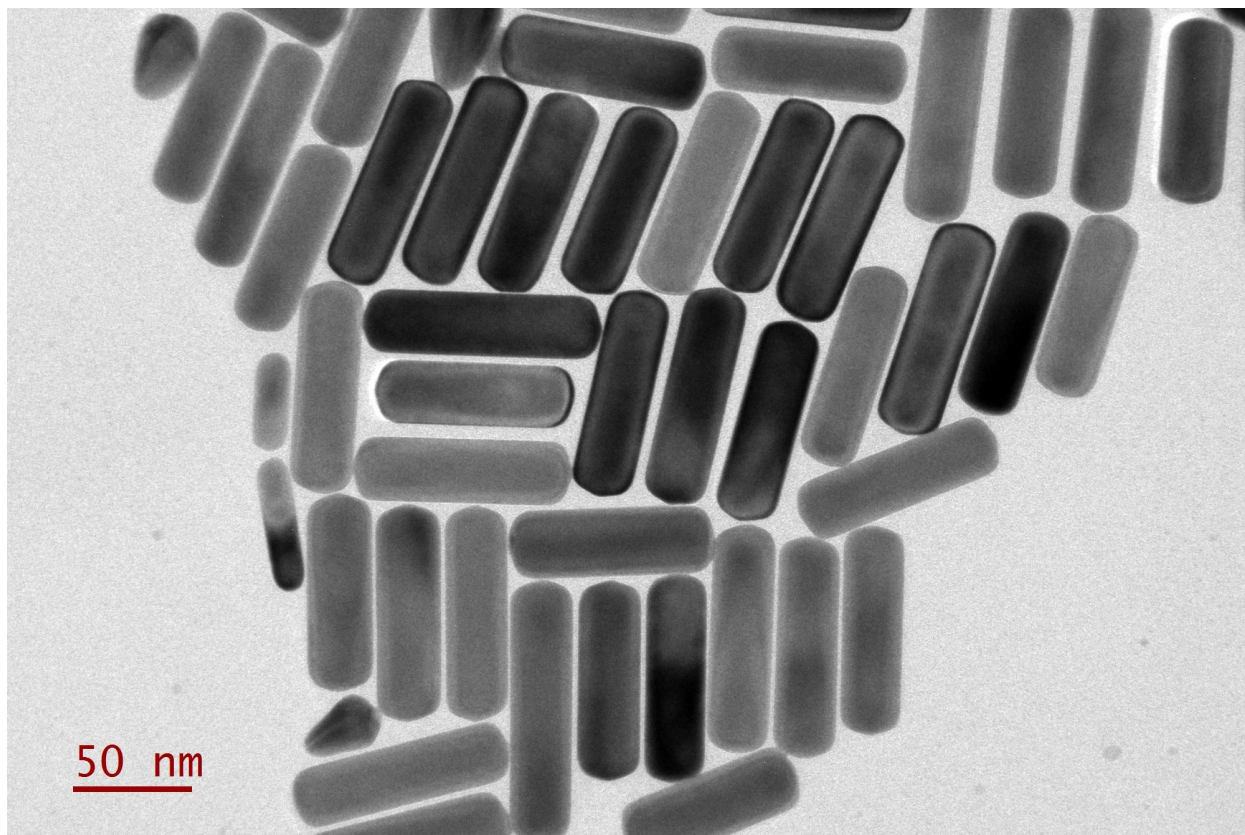


Fig. S3. Transmission electron microscopy (TEM) of gold nanorods. Representative TEM micrograph showing monodisperse rod-shaped Au nanoparticles with rounded ends (typical length ~ 51 nm, diameter ~ 13 nm; aspect ratio ~ 4.1). Scale bar, 50 nm.

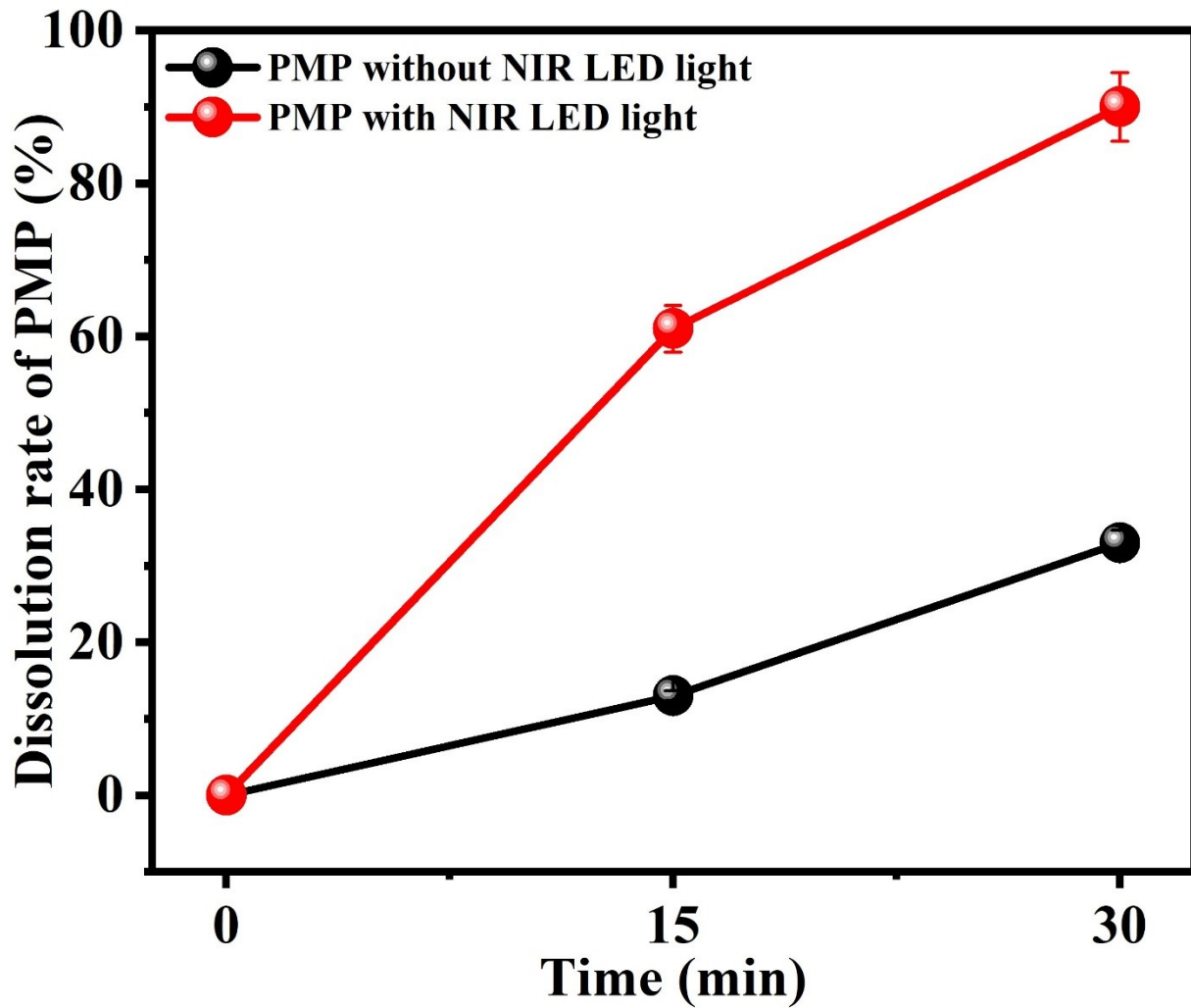


Fig. S4. NIR illumination accelerates dissolution of the photothermal microneedle patch (PMP). Fractional dissolution of the PMP was measured at 0, 15, and 30 min with or without NIR-LED (~780 nm) exposure. NIR-LED markedly increases the dissolution fraction at both time points relative to the no-light control. Data are mean \pm s.d.; replicate numbers are provided in the Methods.

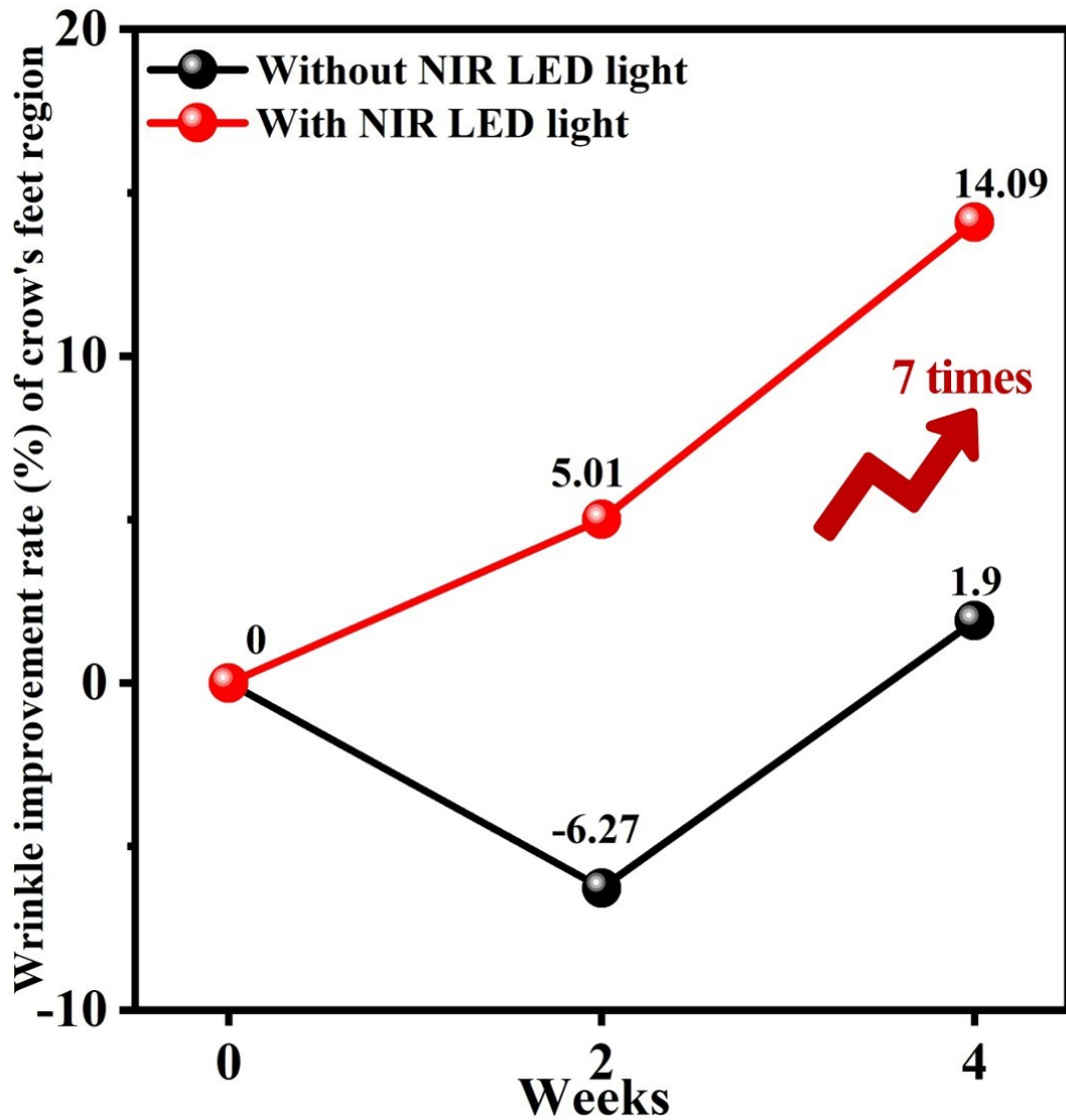


Fig. S5. Crow's-feet wrinkle improvement with and without NIR illumination. Percentage change in wrinkle grade relative to baseline at weeks 2 and 4 for participants using the PMP with NIR-LED versus without NIR-LED. The NIR-LED group shows greater improvement at both time points; by week 4, the mean improvement was ~14.1% with NIR-LED versus ~1.9% without NIR-LED (~7-fold difference). Data are presented as means \pm SD (n = 20 participants).

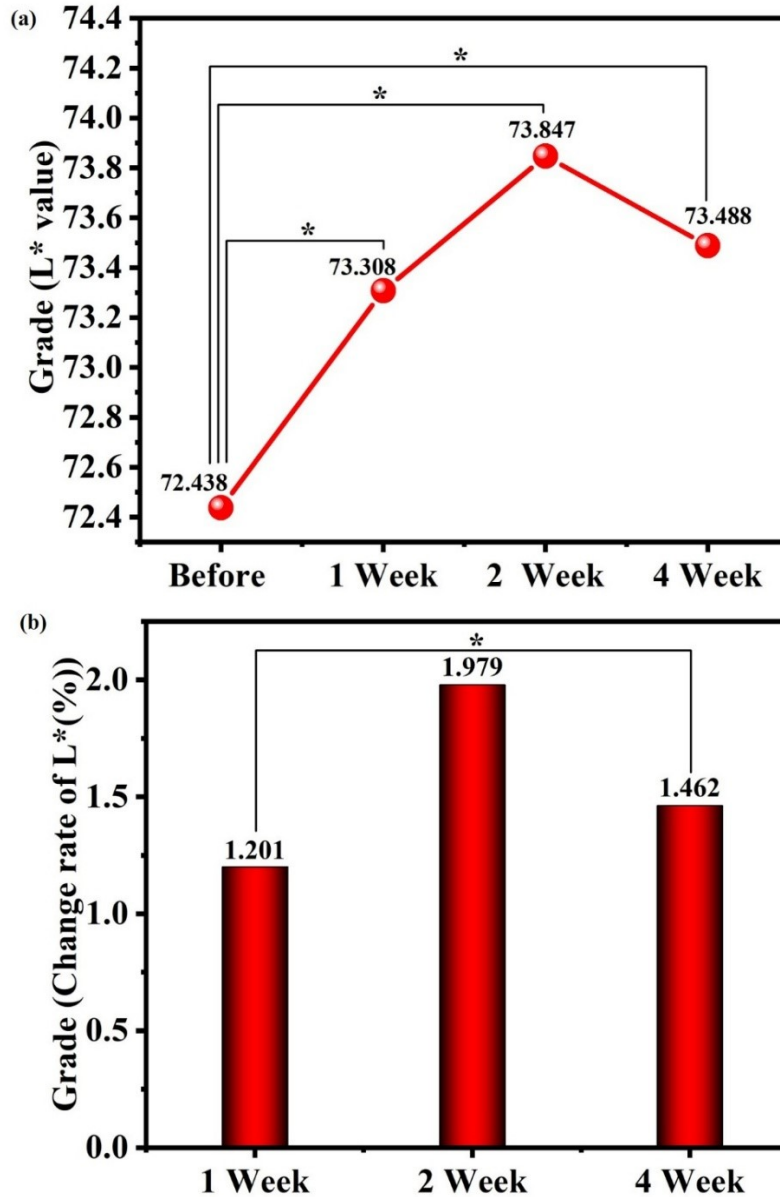


Fig. S6. Brightening of the periorbital skin during treatment with a PMP and NIR LED. (a) VISIA-CR measurements of skin brightness (L^*) at baseline and after 1, 2, and 4 weeks of treatment with the PMP plus NIR-LED. (b) Percentage change in L^* relative to baseline at the same time points. Statistics: repeated-measures ANOVA with Bonferroni-corrected post-hoc comparisons; * indicates $p < 0.05$ versus baseline. Data are presented as means \pm SD ($n = 20$ participants).

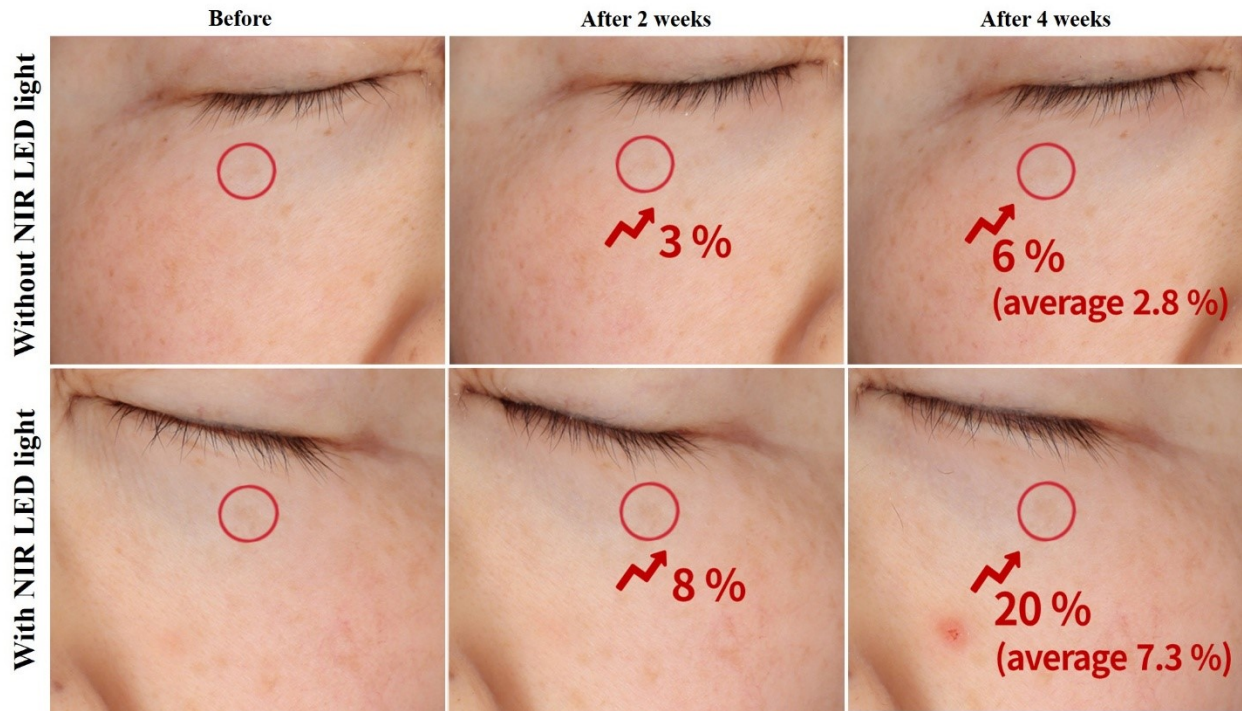


Fig. S7. Reduction of facial pigmentation with a PMP, with and without NIR illumination.

Representative clinical photographs at baseline, 2 weeks, and 4 weeks for treatment without NIR-LED (top row) and with NIR-LED (bottom row). Red circles mark regions of interest used for color analysis. Percent labels denote relative brightening (decrease in melanin/increase in lightness) for the example shown; mean change at week 4 was ~2.8% without NIR-LED and ~7.3% with NIR-LED. The addition of NIR-LED is associated with a greater reduction in pigmented spots by week 4. Data are presented as means \pm SD (n = 20 participants).

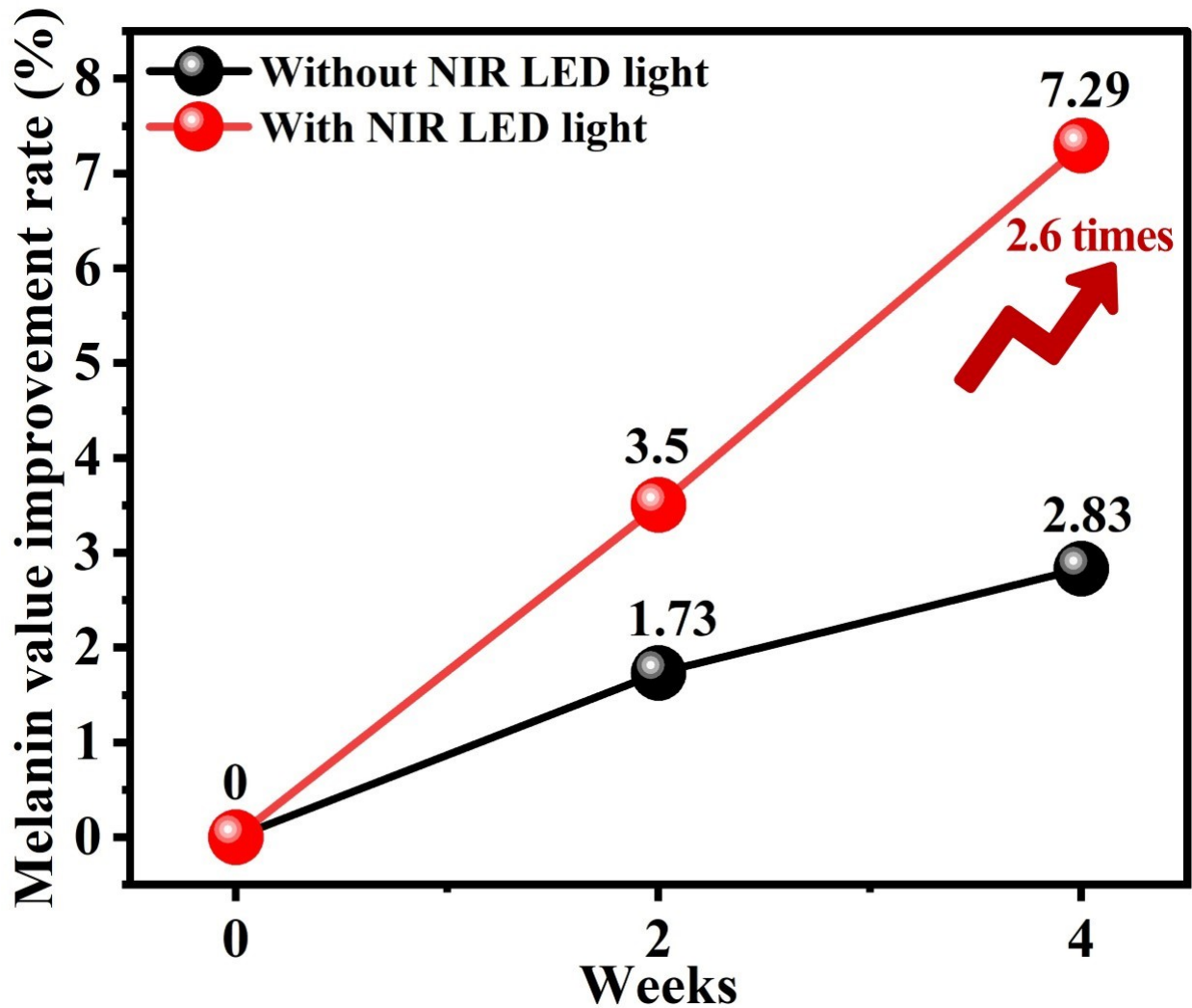


Fig. S8. Reduction in facial melanin with a PMP, with and without NIR illumination. Percentage change in melanin value (lightness increase) at baseline, 2 weeks, and 4 weeks for treatment with NIR-LED versus without NIR-LED. By week 4, the mean improvement was 7.29% with NIR-LED compared with 2.83% without NIR-LED (≈ 2.6 -fold greater). Data are presented as means \pm SD (n = 20 participants).

Table S1. Measure the results of wrinkles around the eyes using PRIMOS.

Weeks	Mean ± SD.	Mean Difference (%)	p-value
Before (0 week)	28.147 ± 8.352		
1 week	25.602 ± 7.889	- 8.658	<0.001*
2 weeks	24.147 ± 7.572	- 13.598	<0.001*
4 weeks	23.417 ± 7.375	- 16.336	<0.001*

**p* <0.017 by Friedman Test, post hoc Wilcoxon Signed Rank Test with Bonferroni correction. Values are expressed as mean ± SD (n = 20 participants).

Table S2. Measure the results of skin brightness using VISIA-CR.

Weeks	Mean ± SD.	Mean Difference (%)	p-value
Before (0 week)	72.438 ± 3.069		
1 week	73.308 ± 2.990	1.201	<0.008*
2 weeks	73.847 ± 2.568	1.979	<0.001*
4 weeks	73.488 ± 3.183	1.462	<0.007*

**p* <0.05 by repeated measures ANOVA, post hoc Bonferroni correction. Values are expressed as mean ± SD (n = 20 participants).