Red Light Emitted Diode (LED) for Skin Rejuvenation: A 16-Week Study

Anita Tangathajinda, Watcharakorn Rattakarn, Jitalada Meephansan*

Department of Dermatology, Chulabhorn International College of Medicine, Thammasart University, Bangkok, Thailand
*Corresponding author, E-mail: kae_mdcu@yahoo.com

Abstract

Improving skin texture and delaying aging is a growing focus in dermatological and cosmetic treatments. LED Red Light therapy, with a wavelength range of approximately 630-660 nm, has gained considerable attention as a non-invasion modality for skin rejuvenation. This study evaluated the efficacy of red-light therapy in enhancing skin texture by promoting collagen synthesis, reducing inflammation, and stimulating cellular repair mechanisms. A cohort of ten participants with mild to moderate Fitzpatrick wrinkle depth scores underwent controlled red-light treatments over sixteen weeks. Objective assessments of Antera 3D image were conducted alongside subjective evaluations to determine improvements in skin pore size, wrinkle depth, and overall firmness. The 16-week study results demonstrated a statistically significant improvement ($p<0.05$) in skin texture and reduced appearance of fine lines and pore size, with minimal side effects reported. These findings suggest that red light therapy represents a non-invasive and cost-effective intervention for skin rejuvenation.

Keywords: *red light, LED, skin rejuvenation, skin aging, red light therapy*

1. Introduction

Skin aging is a complex multifactorial process influenced by intrinsic and extrinsic factors. Internally, genetics and natural aging lead to a decline in cellular function, while external factors such as prolonged sun exposure, pollution, and smoking accelerate skin deterioration (Shin et al., 2023). This evolution creates unsatisfying facial skin expressions such as facial rhytids, decreased collagen synthesis, and loss of elasticity, all of which contribute to an aged and fatigued appearance.

To counteract these effects, various interventions exist, ranging from topical skincare routine to more invasive procedures such as laser therapy, botulinum toxin injections, and surgical facelifts. However, while these methods can restore a youthful appearance, they often come with high costs, potential complications, and extended recovery times. This has led to growing interest in non-invasive, cost-effective alternatives for skin rejuvenation. One such promising modality is low-level light therapy (LLLT) using light-emitting diodes (LEDs)

LLT, especially LED Red Light therapy, has gained attention for its ability to stimulate biological processes that enhance skin quality. FDA-approved for aesthetic use, LED Red Light therapy operates within a specific wavelength range (approximately 630-660 nm) and has been shown to improve facial rhytids and dyschromia while promoting overall skin rejuvenation. This technology has been used for many decades without serious adverse side effects. Unlike more aggressive light-based treatments, such as intense pulsed light (IPL) or fractional lasers, LED red therapy does not cause pain, downtime, or carry the risk of burns and hyperpigmentation, making it an attractive option for individuals seeking safe and effective treatments (Barolet et al., 2009; Couturaud et al., 2023; Ng et al., 2020).

The therapeutic effects of LED Red Light therapy are primarily attributed to photobiomodulation (PMB), a process where light energy penetrates skin tissues and is absorbed by cytochrome C oxidase, a key enzyme in the mitochondrial respiratory chain. This absorption triggers a cascade of cellular responses, including increased mitochondrial ATP production, enhanced metabolic activity, and improved oxygen utilization (Passarella, & Karu, 2014). Additionally, LED Red Light therapy has been shown to reduce oxidative stress, stimulate fibroblast proliferation, and promote neocollegenesis and angiogenesis processes essential for skin repair and rejuvenation. These biological effects translate into enhanced collagen synthesis, improved skin hydration, and better skin texture.

Glass (2021) reviewed the literature on clinical applications of Low-level Light therapy. Among six studies, the LED Red Light therapy had a wavelength of approximately 630nm, combined with other wavelength ranges, significantly improved facial rhytids and dyschromias. Unlike other light-based therapies, such as intense pulsed light (IPL) or fractional lasers, LED Red Light therapy does not cause pain, require downtime, or carry risks of complications such as burns or hyperpigmentation. This makes it an attractive option for a variety of individuals seeking safe, effective, and convenient skin rejuvenation treatments.

This paper aims to provide a comprehensive review of the effects of LED Red Light therapy for skin rejuvenation, with a focus on its underlying mechanisms, clinical efficacy, optimal treatment protocols, and potential limitations. Analyzing existing research and real-world applications highlights the advantages and challenges of integrating LED Red Light therapy into modern dermatological and aesthetic practices. As non-invasive treatment continues to gain popularity, understanding the science behind LED Red Light therapy is crucial for maximizing its benefits and optimizing patient outcomes.

In this study, we specifically investigate the effects of LED Red Light therapy on facial skin, examining its impact on collagen production, skin hydration, and overall skin texture. By conducting controlled studies on facial skin, we aim to provide targeted insights into the effectiveness of red light therapy as a noninvasive approach for facial skin rejuvenation.

2. Objectives

1) To examine the improvement of LED Red Light therapy for facial skin texture
2) To examine the safety of LED Red Light therapy on a subject's facial skin
3) To examine the side effects of LED therapy red light on a subject's facial skin

3. Materials and Methods

3.1 Light Emitted Diode (LED) Light

The LED technology used by SmartLux™ devices that emit a red light with a wavelength of 635 +/- 10 nm, a fluence of 60 Joules/cm2, and an intensity of 4 in accordance with the scientific literature to provide maximum efficiency were selected as the tool. These parameters were selected based on existing literature to ensure maximum efficacy in skin rejuvenation (Barolet et al., 2009). The treatment protocol was designed to balance effectiveness and convenience, requiring one session every two weeks.

Each session lasted 10 minutes, with the device positioned at a fixed distance of 5 cm from the skin surface to ensure consistent light delivery. The total energy delivered per session was 60 J/cm², and participants were instructed to avoid additional light-based treatments during the study period.

3.2 Subjects

3.2.1 Inclusion and Exclusion Criteria

Ten participants were selected for this study through inclusion and exclusion criteria, shown in Table 1.

Table 1 Inclusion and Exclusion criteria

Inclusion criteria	Exclusion criteria
• Male and/or Female with age 25 – 55 years old • Modified Fitzpatrick Wrinkle Scale more than class 1 • Pre-menopause female	• Menopause • Current tobacco use • Tattoos that cover the proposed skin surface • Tattoos that cover the proposed skin surface • Any active skin lesions such as atopic dermatitis, herpes simplex, history of hypertrophic scar, eczema or sunburn • Outdoor workers and sun exposure risk • Have done Botulinum toxin injections within 1 months • Have done Filler injections in the nasolabial fold and periorbital area within 2 weeks • Have done any sort of energy-based device (Lasers) within 1 months • Underlying with Photosensitivity condition including Porphyria, Lupus erythematosus, Rosacea, Solar urticaria • Currently on Vitamin A derivatives or anticoagulants • Pregnant or on Lactation

3.2.2 Justification for Exclusion and Inclusion Criteria

Menopausal women were excluded due to hormonal fluctuations that significantly impact collagen production, skin hydration, and elasticity, which could confuse the result (Gu et al., 2020).

Pre-menopausal females were included because their hormonal stability allows for a more controlled evaluation of LED therapy's effects without the influence of estrogen depletion.

• Other exclusion criteria were set to avoid confounding variables such as sun damage, skin disorders, or recent aesthetic procedures that could affect skin rejuvenation outcomes.

3.3 Methodology

Ten Participants will be selected according to the inclusion and exclusion criteria. Each participant's whole face will undergo LED Red Light therapy for 10 minutes per session, administered once every two weeks over 16 weeks (8 sessions). Then, the patient will be followed up from the baseline every 4 weeks, then 2 weeks after the sessions finish to evaluate the outcome (Weeks 0, 4, 8, 12, and 18). Participants were also instructed to keep a log to record any adverse side effects.

3.4 Outcome Measurements

Subjective Outcome Measurements

Photographs, from the baseline every four weeks, then two weeks after the sessions finish, in frontal view and at a 45-degree angle on each sides. Then, using a modified Fitzpatrick Wrinkle Scale, two blinded board dermatologists will evaluate the results.

Objective Outcome Measurements List Below; Were Taken at Baseline, Followed Up Time (1month, 2 month and 3month)

Antera 3D Miravex, Dublin, Ireland) - A device to assess the skin quality and dynamic wrinkle severity. Three areas on the face, including the mid-forehead, nasolabial fold, and periorbital area, were captured three times at rest and maximum muscle activity. Three filters, including wrinkle-small, pore-small, and skin texture-small, were used to detect the severity of fine wrinkles (FWS) quantitatively, the volume of pores (PV), and the roughness of skin texture (STR) at rest, respectively.

Fine Wrinkle Severity (FWS) – Evaluates fine lines and wrinkles at rest and during muscle contraction.

Pore Volume (PV) – Measures the total pore size and distribution.

Skin Texture Roughness (STR) – Assesses overall skin surface irregularities.

3.5 Statistical Analysis

Data were analyzed using SPSS software (version 30.0.0, IBM, USA).

Paired t-tests were used for normally distributed data, and Wilcoxon signed-rank tests were used for non-normally distributed variables.

Statistical significance was set at $p < 0.05$.

The sample size of ten participants was selected as this study is designed as a pilot investigation to evaluate the preliminary effects of red LED therapy on facial skin rejuvenation.

3.6 Safety and Compliance Monitoring

Adverse effects such as redness, irritation, or discomfort were recorded at each follow-up. Compliance was monitored via participant treatment logs and direct follow-up communications.

4. Results and Discussion

4.1 Results

4.1.1 Visual Outcome

This study was conducted at the Outpatient Department of Dermatology, Samitivej Hospital, Bangkok, Thailand. Ten participants, one male patient and nine female patients, who met the inclusion and exclusion criteria, were enrolled in this study. Of the nine females, only two participants had a Modified Fitzpatrick wrinkle score of 1.5, while the others scored 2. Only one male patient scored 1.5 for the modified Fitzpatrick wrinkle score. No patient withdrew from this study.

Eighty percent of participants had a slight change in Modified Fitzpatrick wrinkle assessment from a 1.5 score to a 1.0 score from baseline to Week 12. Only two participants resulted in no change. The Clinical photographs are shown in Figure 1.

4.1.2 Fine Wrinkles Assessment

The severity of small fine wrinkles (0.1-1mm) was assessed by Antera 3D (Miravex, Dublin, Ireland). The results of Antera 3D demonstrated a statistically significant ($p<0.005$) improvement of fine wrinkles every week compared to baseline at the cheek, forehead, and nasolabial fold (NLF). While fine wrinkles at each week simultaneously improved, there was no statistically significant improvement except from Weeks 4 to 8 of the left cheek and right NLF, and from Weeks 6 to 8, both sides of the forehead and left cheek had statistically significant improvement of wrinkle as seen in Table 1, and further confirmed continued improvements over time.

Figure 2 indicates an overall reduction in fine wrinkles over time across all three areas. The forehead showed the most noticeable decline initially but experienced some fluctuations, particularly from Weeks 4 to 6, before continuing to improve. The Cheek and NLF showed a steady decline, with the Cheek reaching the lowest wrinkle severity by Week 8. The fluctuations observed in the forehead and other regions may be attributed to variations in skin response to treatment, natural skin regeneration cycles, or external factors influencing wrinkle measurements.

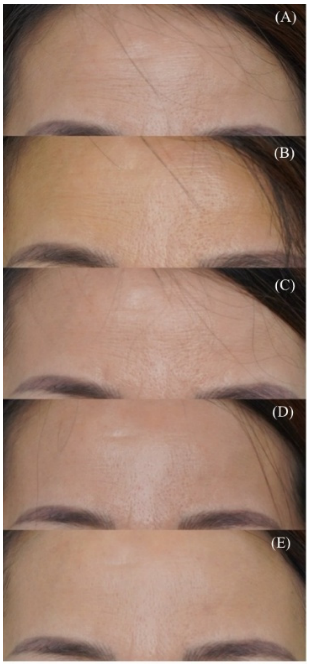

Figure 1 The change in modified Fitz Patrick wrinkle scale improvement at upper forehead at Baseline (A), Week 2 (B), Week 4 (C), Week 6 (D) and Week 8 (E) weeks. From Baseline (A), the skin appears textured with visible fine lines and uneven pores. Then, from Week 2 (B) to Week 8 (E), shows a gradual improvement in forehead fine lines, improving skin texture and evening out the complexion

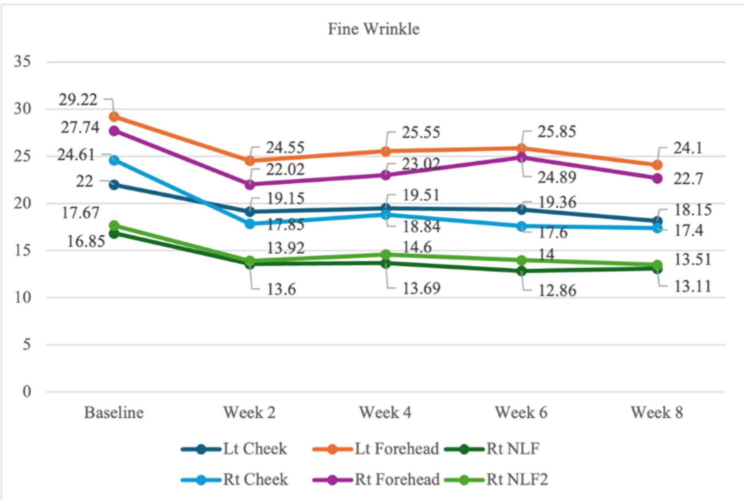

Figure 2 The graph shows a marked decrease in fine wrinkles at the Cheek, Forehead, and Nasolabial fold (NLF) areas on both sides from Baseline to Week 8

Table 1 Wilcoxon Rank test of Fine Wrinkles of Cheek, Forehead, and NLF on both sides

Fine Wrinkles	Left			Right		
	Mean	**Z**	**p-value**	**Mean**	**Z**	**p-value**
Cheek						
1. - Baseline	22	-2.8	*0.005*	24.61	-2.8	*0.005*
- Week 2	19.15			17.85		
2. - Baseline	22	-2.8	*0.005*	24.61	-2.8	*0.005*
- Week 4	19.51			18.84		
3. - Baseline	22	-2.8	*0.005*	24.61	-2.8	*0.005*
- Week 6	19.36			17.6		
4. - Baseline	22	-2.8	*0.005*	24.61	-2.8	*0.005*
- Week 8	18.15			17.4		
5. - week 4	19.51	-2.395	*0.017*	18.84	-1.682	0.093
- week 8	18.15					
6. - week 6	19.36	-1.99	*0.047*	17.6	-1.07	0.285
- week 8	18.15			17.4		
Forehead						
1. – Baseline	29.22	-2.803	*0.005*	27.74	2.41	0.039
-Week 2	24.55			22.02		
2. – Baseline	29.22	-2.803	*0.005*	27.74	2.75	0.023
-Week 4	25.55			23.02		
3. – Baseline	29.22	-28.03	*0.005*	27.74	2.7	0.024
-Week 6	25.85			24.89		
4. – Baseline	29.22	-2.803	*0.005*	27.74	2.7	0.024
-Week 8	24.1			22.7		
5. – Week 6	25.85	-2.09	*0.037*	24.89	2.7	0.025
-Week8	24.1			22.7		
NLF						
1.-Baseline	16.85	-2.803	*0.005*	17.67	3.694	*0.005*
-Week2	13.6			13.92		
2.-Baseline	16.85	-2.803	*0.005*	17.67	3.698	*0.005*
-Week4	13.69			14.6		
3. -Baseline	16.85	-2.803	*0.005*	17.67	3.764	*0.004*
-Week6	12.86			14		
4.-Baseline	16.85	-2.803	*0.005*	17.67	5.894	*<0.001*
-Week8	13.11			13.51		
5.-Week 4	13.69	-1.58	*0.114*	14.6	2.897	*0.018*
-Week8	13.11			13.51		

4.1.3 Pore Size Assessment

Small Pore size was detected by Antera 3D Scan. Table 2 shows measurements on both left and right cheek, forehead, and NLF indicated a significant reduction in all subsequent weeks (P-values ≤ 0.005). For cheeks and forehead area, further pairwise comparisons among the later weeks (such as Week 4 versus Week 8, and Week 6 versus Week 8) also supported their improvements. In contrast, only Week 4 to Week 8 showed statistically significant differences in improvement of pore sizes (P-values 0.03)

Table 2 Wilcoxon Rank test of Pore size of Cheek, Forehead, and NLF on both sides

Pore size	**Left**			**Right**		
	Mean	**Z**	**p-value**	**Mean**	**Z**	**p-value**
Cheek						
1. - Baseline	10.57	-2.701	*0.007*	13.99	-2.803	*0.005*
- Week 2	8.82			8.34		
2. - Baseline	10.57	-2.803	*0.005*	13.99	-2.803	*0.005*
- Week 4	9.25			9.25		
3. - Baseline	10.57	-2.803	*0.005*	13.99	-2.803	*0.005*
- Week 6	8.89			8.87		
4. - Baseline	10.57	-2.803	*0.005*	13.99	-2.803	*0.005*
- Week 8	8.13			6.49		
9. - week 4	9.25	-2.09	*0.037*	9.25	-1.17	0.241
- week 8	8.13			8.68		
10. - week 6	8.89	-2.09	*0.037*	8.87	-0.968	0.333
- week 8	8.13			8.68		
Forehead						
1. – Baseline	14.75	3.012	*0.015*	13.47	3.45	0.007
- Week 2	11.64			10.42		
2. – Baseline	14.75	3.869	*0.004*	13.47	3.3	0.009
- Week 4	12.8			10.85		
3. – Baseline	14.75	5.361	*<0.001*	13.47	4.88	0.001
- Week 6	12.57			11.12		
4. – Baseline	14.75	4.81	*0.001*	13.47	3.91	0.004
- Week 8	11.2			10.72		
9. – Week 4	12.8	3.111	*0.012*	10.85	0.232	0.814
- Week8	11.2			10.72		
10. – Week 6	12.57	2.799	*0.021*	11.12	0.914	0.385
- Week8	11.2			10.72		
NLF						
1.-Baseline	7.52	2.94	*0.017*	7.89	3.171	*0.011*
-Week2	5.4			5.76		
2.-Baseline	7.52	3.48	*0.007*	7.89	2.874	*0.018*
-Week4	5.43			6.22		
3. -Baseline	7.52	3.42	*0.008*	7.89	3.277	*0.01*
-Week6	4.9			5.62		
4.-Baseline	7.52	3.43	*0.008*	7.89	4.03	*0.003*
-Week8	5.2			5.5		
9.-Week 4	5.43	1.07	*0.313*	6.22	2.56	*0.03*
-Week8	5.2			5.5		

Figure 3 illustrates a reduction in pore size over the eight weeks across all facial areas. The forehead areas started with the largest pore sizes but saw steady improvement, whereas the nasolabial folds showed the smallest values but also improved over time. The most significant reductions occurred in Week 2 and Week 8. The rapid decrease in pore size in Week 2 may be attributed to an initial skin response, possibly an initial skin response, conceivably due to hydration or early treatment effects. The continued but slower decline afterward suggests a stabilization phase, with Week 8 marking another significant improvement, likely due to cumulative treatment effects and ongoing skin remodeling.

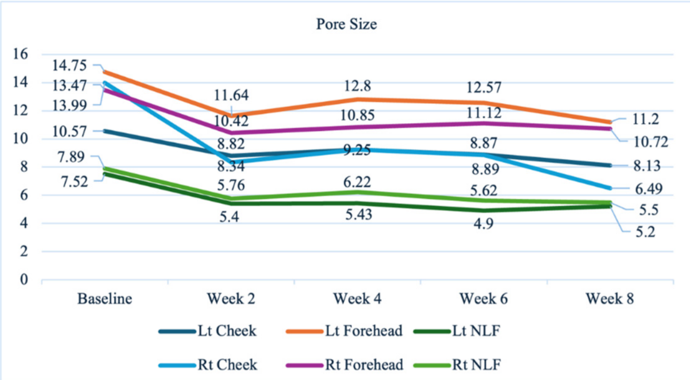

Figure 3 The graph shows a reduction of Pore size at the Cheek, Forehead, and Nasolabial fold (NLF) areas on both sides from Baseline to Week 8

4.1.4 Texture Assessment

The skin texture on both cheeks, NLF, and forehead improved significantly over time. For the left cheek, the Wilcoxon test confirmed that baseline comparisons with Weeks 2, 4, and 8 were statistically significant (P-values $\leq$ 0.005). Similar significant improvements were also seen on the right cheek. Both the left and right forehead showed significant improvements in texture from Baseline to all subsequent weeks (P-values $\leq$ 0.005), with further enhancement from Week 6 to Week 8 (p=0.037) on the left forehead but no difference on the right side. Both sides of NLF also demonstrated significant improvement from Baseline to every treatment week, with an additional significant difference when comparing Week 2 to Week 8 (p=0.028), as shown in Table 3.

Figure 4 indicates an overall improvement in skin texture over 8 weeks. While there were minor fluctuations around Week 6, the general trend shows a steady decline in texture roughness, suggesting smoother skin. These fluctuations may be attributed to natural variations in skin regeneration cycles or temporary environmental factors such as hydration levels or external influences affecting skin texture measurements. Despite these mid-study variations, the forehead improved, and the nasolabial folds showed the most significant improvement. The forehead experienced some mid-study fluctuations before ultimately improving.

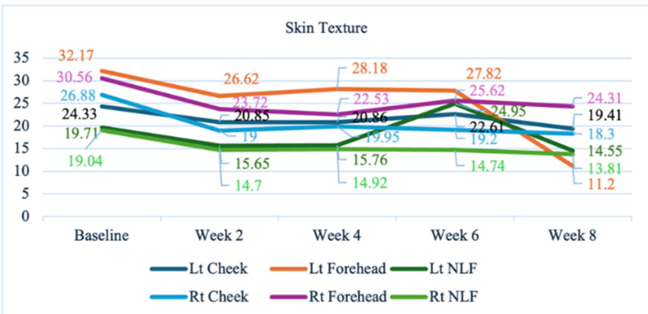

Figure 4 The graph shows improvement of Skin texture at the Cheek, Forehead, and Nasolabial fold (NLF) areas on both sides from Baseline to Week 8

Table 3 Wilcoxon Rank test of Skin Texture of the Cheek, Forehead, and NLF on both sides

Pore size	**Left**			**Right**		
	Mean	**Z**	**p-value**	**Mean**	**Z**	**p-value**
Cheek						
1. - Baseline	24.33	-2.8	*0.005*	26.88	-2.8	*0.005*
- Week 2	20.85			19.00		
2. - Baseline	24.33	-2.8	*0.005*	26.88	-2.8	*0.005*
- Week 4	20.86			19.95		
3. - Baseline	24.33	-1.78	*0.07*	26.88	-2.8	*0.005*
- Week 6	22.61			19.20		
4. - Baseline	24.33	-2.7	*0.007*	26.88	-2.8	*0.005*
- Week 8	19.41			18.3		
Forehead						
1. – Baseline	32.17	-2.8	*0.005*	30.56	3.23	0.01
-Week 2	26.62			23.72		
2. – Baseline	32.17	-2.8	*0.005*	30.56	3.57	0.006
-Week 4	28.18			22.53		
3. – Baseline	32.17	-2.8	*0.005*	30.56	5.50	<0.001
-Week 6	27.82			25.62		
4. – Baseline	32.17	-2.8	*0.005*	30.56	3.86	0.004
-Week 8	11.2			24.31		
10. – Week 6	27.82	-2.09	*0.037*	25.62	1.244	0.245
-Week8	26.09			24.31		
NLF						
1. - Baseline	19.71	-2.8	*0.005*	19.04	4.45	*0.005*
- Week 2	15.65			14.7		
2. - Baseline	19.71	-2.8	*0.005*	19.04	4.25	*0.005*
- Week 4	15.76			14.92		
3. - Baseline	19.71	-2.8	*0.005*	19.04	4.38	*0.005*
- Week 6	14.95			14.74		
4. - Baseline	19.71	-2.8	*0.005*	10.94	6.23	*0.005*
- Week 8	14.55			13.81		
9. - week 4	15.76	-1.48	*0.139*	14.92	2.782	0.021
- week 8	14.55			13.81		
10. - week 6	14.95	-0.87	*0.386*	14.74	2.48	0.0353
- week 8	14.55			13.81		

4.1.5 Side Effects

No adverse side effects were reported during this study. Only mild erythema after LED Red Light therapy was reported, but after 1-2 hours, it was resolved.

4.2 Discussion

The results from this study indicate that LED Red Light therapy effectively improves skin quality, as evidenced by reducing fine wrinkles, minimizing pore size, and enhancing skin texture across multiple facial areas (cheek, nasolabial fold, and forehead). The significant improvements observed over the eight weeks align with previous studies. Highlighting the photobiomodulated effects of low-level light therapy (LLLT) on skin rejuvenation and can be attributed to the molecular mechanisms triggered by Red LED therapy (630-660nm). This wavelength range has been widely studied for its ability to modulate cellular processes at the mitochondrial and extracellular matrix (ECM) levels, leading to enhanced skin repair and anti-aging effects (Barolet et al., 2009; Couturaud et al., 2023; Ng et al., 2020). However, this study offers new insights by demonstrating a unique pattern of an initial improvement followed by a temporary plateau and sustained enhancement even after treatment cessation, suggesting prolonged cellular benefits beyond direct LED exposure.

4.2.1 Biological Mechanisms Underlying Skin Improvement

One of the primary mechanisms of LED Red Light therapy is the activation of cytochrome c oxidase (COX) in mitochondria, results in increased ATP production. Higher ATP levels provide more energy for cellular functions, particularly in fibroblasts and keratinocytes, leading to enhanced tissue repair, collagen synthesis, and epidermal renewal (Lan et al., 2019). This directly correlates with the improvements in skin texture and wrinkle reduction observed in this study.

There were marked enhancements of wrinkles, pore size, and skin texture from Baseline to Week 2. This can be explained by the first facial exposure to Red light therapy as a result of Week 2. Additionally, neocollegenesis begins 3 to 4 weeks after initial exposure, leading to gradual wrinkle reduction and increased skin firmness over time. This also aligns with the significant reductions in pore size observed in this study, particularly in the forehead and cheeks, where sebaceous gland activity is higher. After our body tends to tolerate the same amount of red light flux for Week 4 and Week 6, this explains a slight increase at Week 4 and Week 6 with minimal fluctuations. This results in enhanced synthesis of mature collagen fibrils, which replace fragmented or damaged collagen fibers, leading to reduced fine wrinkles over time, whereas Matrix Metalloproteinases (MMPs), particularly MMP-1 and MMP-9, are downregulated, thereby preventing excessive collagen degradation and maintaining skin integrity (Lee et al., 2007; Mota et al., 2023).

Two weeks after no exposure (at 8 weeks), there was a significant improvement in all skin wrinkles, pore size, and facial textures. This shows that once the cellular responses via photobiomodulated have been activated. It then gives sustained effects after post-treatment since the collagen life cycle takes several months. The benefits continued even without further stimulation.

Interestingly, our study found a slight plateau in Weeks 4 and 6, where improvements slowed. This could be due to cellular adaptation to repeated LED Red Light exposure, a phenomenon where the same light flux elicits a diminished response over time. However, after treatment cessation at Week 8, improvements in wrinkles, pore size, and texture were observed, suggesting sustained biological activity post-treatment, likely due to ongoing collagen remodeling and ECM stabilization.

4.2.2 Comparison with Previous Studies

These findings align with prior research demonstrating significant improvements in wrinkles and collagen synthesis following LED Red Light therapy (Glass, 2021). However, this study introduces two key differences. First, while previous studies mainly assessed short-term outcomes, our results suggest that biological activity persists even after treatment cessation, indicating a prolonged therapeutic window.

Second, while most research has reported gradual, linear improvements, this study identified a non-linear response characterized by early improvement, mid-treatment stabilization, and post-treatment enhancement. These insights suggest that adjusting treatment intervals or incorporating rest periods may optimize results in clinical practice.

4.2.3 Study Limitations

Despite its promising findings, this study has several limitations. The small sample size (n = 10) limits statistical power, making it difficult to generalize findings to a broader population. Additionally, the lack of a control or placebo group prevents definitive conclusions about whether observed effects are solely due to LED Red Light therapy or influenced by natural skin turnover. Moreover, while the study attributes cellular and molecular changes to ATP production, collagen synthesis, and MMP inhibition, no direct biochemical measurements were performed to confirm these mechanisms. Future research should incorporate biochemical assays, molecular markers, or skin biopsies to validate the underlying processes. Lastly, the follow-up period was limited to two weeks post-treatment, leaving questions about long-term durability and optimal maintenance schedules.

4.2.4 Clinical Implications

These findings allude that LED Red Light therapy is a viable non-invasive treatment for skin rejuvenation, particularly for wrinkle reduction, pore refinement, and texture enhancement. Given its safety, ease of use, and prolonged effects, it may serve as a standalone therapy for individuals seeking gradual, long-lasting improvements. However, for maximized efficacy, combining Red LED therapy with other anti-aging treatments, such as topical retinoids, antioxidants, or microneedling, could further enhance collagen synthesis and skin renewal.

5. Conclusion

The overall results suggest that Red LED therapy is effective in improving the appearance of facial skin by significantly reducing of facial skin by significantly reducing fine wrinkles, decreasing pore size, and enhancing skin texture over time and post-treatment. Each facial region, cheek, nasolabial fold, and forehead - showed progressive and statistically significant improvements, supporting the use of Red LED therapy as a non-invasive treatment modality for facial rejuvenation. The consistency across various statistical analyses reinforces that the observed skin improvements are robust and not due to chance.

For optimal results, Red LED therapy is recommended once every two weeks, with 8-10 sessions producing visible and long-lasting improvements. Although improvements persisted at Week 8, further research might need to determine when the effects begin to diminish or whether the duration of maintenance sessions of periodic Red LED therapy. While Red LED therapy is effective as a standalone treatment, it may be further enhanced when combined with other dermatological interventions. Moreover, other objective and subjective measurements should take in consideration for further study in order to ensure every aspect.

This detailed analysis demonstrates that Red LED therapy offers a promising approach to addressing multiple signs of skin aging simultaneously, thereby providing a holistic benefit in facial skin appearance.

6. Acknowledgements

The author would like to thank all staff at the Department of Dermatology, CICM Thammsart University, and the Department of Dermatology, Samitivej Hospital, for their guidance and consultation throughout this research.

7. References

Barolet, D., Roberge, C. J., Auger, F. A., Boucher, A., & Germain, L. (2009). Regulation of skin collagen metabolism in vitro using a pulsed 660 nm LED light source: clinical correlation with a single-blinded study. *Journal of Investigative Dermatology*, 129(12), 2751-2759. https://doi.org/10.1038/jid.2009.186

Couturaud, V., Le Fur, M., Pelletier, M., & Granotier, F. (2023). Reverse skin aging signs by red light photobiomodulation. *Skin Research and Technology*, 29(7), e13391. https://doi.org/10.1111/srt.13391

Glass, G. E. (2021). Photobiomodulation: A review of the molecular evidence for low level light therapy. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *74*(5), 1050-1060. https://doi.org/10.1016/j.bjps.2020.12.059

Gu, Y., Han, J., Jiang, C., & Zhang, Y. (2020). Biomarkers, oxidative stress and autophagy in skin aging. *Ageing Research Reviews*, 59, 101036. https://doi.org/10.1016/j.arr.2020.101036

Lan, C. E., Hung, Y. T., Fang, A. H., & Ching-Shuang, W. (2019). Effects of irradiance on UVA-induced skin aging. *Journal of Dermatological Science*, *94*(1), 220-228. https://doi.org/10.1016/j.jdermsci.2019.03.005

Lee, S. Y., Park, K. H., Choi, J. W., Kwon, J. K., Lee, D. R., Shin, M. S., Lee, J. S., You, C. E., & Park, M. Y. (2007). A prospective, randomized, placebo-controlled, double-blinded, and split-face clinical study on LED phototherapy for skin rejuvenation: clinical, profilometric, histologic, ultrastructural, and biochemical evaluations and comparison of three different treatment settings. *Journal of Photochemistry and Photobiology B: Biology*, 88(1), 51-67. https://doi.org/10.1016/j.jphotobiol.2007.04.008

Mota, L. R., Duarte, I. D. S., Galache, T. R., Pretti, K., Neto, O. C., Motta, L. J., Horliana, A., Silva, D., & Pavani, C. (2023). Photobiomodulation reduces periocular wrinkle volume by 30%: a randomized controlled trial. *Photobiomodulation, Photomedicine, and Laser Surgery*, *41*(2), 48-56. https://doi.org/10.1089/photob.2022.0114

Ng, J. N. C., Wanitphakdeedecha, R., & Yan, C. (2020). Efficacy of home-use light-emitting diode device at 637 and 854-nm for facial rejuvenation: A split-face pilot study. *Journal of Cosmetic Dermatology*, 19(9), 2288-2294. https://doi.org/10.1111/jocd.13613

Passarella, S., & Karu, T. (2014). Absorption of monochromatic and narrow band radiation in the visible and near IR by both mitochondrial and non-mitochondrial photoacceptors results in photobiomodulation. *Journal of Photochemistry and Photobiology B: Biology*, *140*, 344-358. https://doi.org/10.1016/j.jphotobiol.2014.07.021

Shin, S. H., Lee, Y. H., Rho, N. K., & Park, K. Y. (2023). Skin aging from mechanisms to interventions: focusing on dermal aging. *Frontiers in Physiology*, 14, 1195272. https://doi.org/10.3389/fphys.2023.1195272