Assessment of Optical Skin Properties Following Different Laser Energy Densities Using Non-Invasive Biophysical Measurements

Abstract

Background: Acute and chronic skin lesions continue to be a considerable medical problem as they hinder the process of tissue recovery due to prolonged inflammation and the likelihood of complications. Low-Level Laser Therapy (LLLT), also referred to as photobiomodulation, has been utilized to enhance the process of skin wound healing as it improves cell functioning and activities related to inflammatory reactions. Nevertheless, additional evidence still needs to be collected in the process of clinical examination to explain its efficiency in relation to skin wound healing and inflammatory markers.

Objective: The goal of this study was to investigate the efficiency of Low-Level Laser Therapy in skin wound treatment on the basis of clinical signs, information concerning inflammatory markers, tissue perfusion, and pain intensity levels.

Methods: A randomized prospective controlled clinical study was done on patients suffering from superficial skin injuries. A total of 360 subjects were recruited for the study and divided into experimental (low-level laser therapy (LLLT)) and control (standard management) groups. Weekly clinical assessments were done for four weeks. During the study, wound healing data was collected in terms of wound healing percentage, and serum concentrations of TNF-α, IL-6, and CRP were measured pre-and post-study. Pain status was evaluated by the VAS test, while tissue perfusion was studied by a non-invasive method. Statistical analysis was conducted appropriately, and a P-value of less than 0.05 was used to indicate statistical significance.

Results: Low-Level Laser Therapy was shown to close the wounds significantly better than the control group. In fact, lowest level laser therapy was able to achieve 91.8% closure rate as compared to 68.3% achieved by the control group at Week 4 ($P < 0.001$). There were significant decreases in TNF-alpha, IL-6 and CRP concentration in the blood after laser treatment compared to traditional treatment ($P < 0.001$). At the same time, the pain level of patients was lower after laser treatment and tissue perfusion was higher, complete healing and patient satisfaction were also higher.

Conclusion: Laser therapy at low levels can significantly speed up the healing of wounds. This is possible because low-level laser therapy reduces inflammation, improves blood circulation, and helps with recovery. These results encourage the use of the technique - photobiomodulation, in the treatment of wounds of human skin.

Keywords: Low-Level Laser Therapy; Photobiomodulation; Healing of Wounds; Inflammatory Biomarkers; TNF-α; Interleukin-6; C-Reactive Protein; Healing of Tissues.

Introduction

Healing of skin wounds is a biological process that has multiple stages such as bleeding control, inflammation, tissue regeneration, and tissue remodeling (1,2). It is important to control the process of cell migration, fibroblast proliferation, neo-vascularization, applying of extracellular matrix, collagen synthesis, and re-epithelialization to ensure the process is efficient. Problems with the normal course of these processes may lead to improper healing, chronic wounds, larger scars formation, and higher risk of possible infections (1,2).

The role of inflammation during the early phase of wound healing is crucial for the elimination of pathogens and the start of tissue repair. However, excessive or prolonged inflammation causes delay in the transition to the proliferative phase and results in chronic wounds (2,3). Increased levels of such pro-inflammatory cytokines as tumor necrosis factor alpha (TNF-α), interleukin 6 (IL-6), C-reactive protein (CRP), oxidative stress and activation of nuclear factor kappa B (NF-κB) signaling pathway have been linked to impaired tissue regeneration (3–5). Thus, the search for methods that can control inflammation and enhance regeneration of tissue has become an important area of regenerative medicine.

Low-level laser therapy (LLLT), or photobiomodulation (PBM), is a new non-invasive therapeutic technique that can stimulate healing of tissues with no thermal injuries (6–8). In contrast to high-power surgical lasers, laser gingival therapy uses low energy monochrome light that is absorbed

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mainly by cytochrome c oxidase in mitochondria. The given interaction enhances ATP generation, controls ROS release, activates fibroblast proliferation, contributes to the formation of collagen, promotes angiogenesis, and ensures the restoration of epithelial tissues (7–9).
Besides the enhancement of tissue repair, PMB has a strong anti-inflammatory effect by decreasing the level of pro-inflammatory cytokines, improving microcirculation in the affected area, increasing tissue oxygenation, and modulating macrophage activity and extracellular matrix remodelling (8–10). All of the aforementioned biological reactions create a favorable environment for the healing of wounds and have been proven by both laboratory and clinical studies (7–10).
An objective assessment of wound healing requires more than just a visual evaluation. Current research into wound healing incorporates both clinical observations and use of inflammatory biomarkers, as well as non-invasive measurements. Serum levels of TNF-α, IL-6 and CRP provide quantifiable evidence of general inflammation while assessment of tissues perfusion and temperature provide valuable information about local recovery (2,8). The use of various measurement technologies means that wound healing can be assessed more accurately than conventional observation.
Studies carried out by our research group have demonstrated that targeting the inflammatory pathways is biologically justified in the process of tissue regeneration. Indeed, the findings of Hadi et al. show that inhibiting apoptosis and inflammatory response reduces tissue damage caused by myocardial ischaemia-reperfusion, underscoring the need to control inflammation for successful tissue repair (11). Furthermore, findings of Hadi et al. shed light on the role of NF-κB-mediated oxidative pathways, confirming that manipulating these pathways can benefit regenerative outcomes (12). Sadiq et al. further support the findings of Hadi et al. arguing for the clinical relevance of C-reactive protein as a biomarker of inflammation (13). In addition, Yousif et al. inform that regenerative treatments improve the patients receiving stem cell transplants (14).
While many studies have been carried out on photobiomodulation, there are still significant inconsistencies concerning laser wavelength, energy density, irradiation method, time spent on treatment, and assessment of outcomes (6–10). As a result, clinical outcomes are often contradictory, and there are currently no standard protocols in therapy. It is worth mentioning, furthermore, that there have only been a few clinical trials in which the effects of the above-mentioned procedures on the healing of wounds were analyzed together with the inflammatory biomarkers and physical parameters of the patients.
That is why the aim of the present study is to evaluate the efficiency of Low-Level Laser Therapy along with normal wound care by making use of clinical evaluation and laboratory study of inflammatory biomarkers and non-invasive study of physical parameters. By studying the process of closure of the wound, inflammation processes, tissue perfusion, pain, and patient-centered outcomes simultaneously, this study is expected to help find out all the benefits of photobiomodulation in healing wounds and the tissue regeneration process.

Materials and Methods

Study Design

This controlled, prospective, randomised clinical study was designed to assess the efficacy of low-level laser therapy (LLLT) as an adjunct treatment to the standard wound care process to promote the healing of skin wounds and modulate **inflammatory biomarkers.** A combination of various clinical, laboratory and non-invasive biophysical evaluations was performed as part of the study. The participants were randomly assigned into two groups (intervention group that received LLLT as an adjunct to standard wound care and control group that received only standard wound care), which was carried out repeatedly in the ratio of 1:1. The study protocol followed the principles of good clinical practice as well as those of the Declaration of Helsinki.

Study Setting

The study was performed at outpatient clinics for wound treatment and dermatology in a specialised medical centre, lasting for six months. The procedures of recruiting patients, delivering laser treatments, performing the follow-up, conducting laboratory research as well as biophysical measurements were carried out strictly according to a pre-established standardised protocol by trained health care personnel.

Study Population

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At the outset, 360 individuals who bore superficial wounds or partial thickness wounds were recruited in the study. The patients were randomly distributed into two groups:
• **Group A (Intervention group):** 180 individuals were given Low-Level Laser Treatment together with standard treatment for wound healing.
• **Group B (Control group):** 180 subjects were approached with standard wound healing treatment.

Eligibility Criteria
Inclusion Criteria
In order to participate, the subjects should satisfy the following eligibility requirements:
• Age within the limit of 18 to 65.
• Existence of a superficial or partially thick wound.
• Duration of the wound ranging from 7 to 30 days.
• Size of the wound allowing for digital measurements.
• Ability to follow the doctors for treatment sessions.
• Providing the informed consent in written form.
Exclusion Criteria
Patients were considered ineligible if they presented one of the following conditions:
• Diabetes mellitus not under control.
• Severe systemic infection.
• Malignant skin tumors.
• Autoimmune skin conditions.
• Photosensitivity disorders.
• Pregnant women or women who are breastfeeding.
• The preceding laser treatment at the site of the lesion.
• Someone who is taking immunosuppressants.
• Serious injuries that should be treated surgically.

Sample Size
360 patients participated in the research, and each group consisted of 180 patients. The number of participants was adequate to reveal important differences in wound healing and inflammatory parameters with sufficient statistical power.

Randomisation
The allocation of members of the study into experimental and control groups was done randomly over a computer-generated randomisation table by means of a 1:1 ratio and thereby to try and avoid bias in member selection and ensure that the groups have comparable baseline measurements.
Intervention Protocol
Besides the standard wound treatment, members in the experimental group underwent Low-Level Laser Therapy process, which was performed by a diode laser, operating at a wavelength of 660 nm, an output power of 100 mW, and energy density of 4 J/cm^2, and applied in continuous-wave form. The respective irradiation process was applied within the wound margins and directly at the wound area on a three times a week basis during four weeks of treatment.
During the entire process of laser application, both the patient and the staff member performing the procedure wore laser protection glasses.

Laser Parameters

Parameter	**Specification**
Laser type	Diode laser
Wavelength	660 nm
Output power	100 mW
Energy density	4 J/cm^2
Operating mode	Continuous
Treatment frequency	Three sessions per week

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Parameter	Specification
Treatment duration	Four weeks
Application site	Wound margins and wound bed

Standard Wound Care

All subjects in the study received the same wound care that was standardized. Standard wound care consisted of the cleaning of the wound with sterile normal saline, the cleaning of necrotic tissue when necessary, and application of sterile wound dressing. Topical agents like growth factors, biological dressings, platelet-rich plasma, and advanced drugs for wound healing were not used to prevent bias.

Clinical Assessment

Clinical evaluation was done before the start of the treatment and once a week during the four weeks of treatment. Standardized photographs were taken using the same camera settings, lightning conditions, and distance from the wound. To measure the wound area, digital wound measuring techniques were used.

Clinical outcomes include:

- Percentage of wound closure
- Local erythema
- Oedema
- Wound exudate
- Pain in the area
- Complete wound healing

Biophysical evaluation

An objective biophysical evaluation of the study population was done under controlled environmental conditions. The skin temperature around the wound was measured using thermal imaging or infrared thermometer. Tissue perfusion was examined using Laser Doppler Flowmetry wherever available. Measurements were made before the commencement of the therapy and after the completion of therapy.

Inflammatory Biomarker Assessment

The venous blood samples were collected at baseline and after 4 weeks of therapy. Serum was separated and analyzed as per standard laboratory practices.

The following inflammatory biomarkers were quantified:

- TNF-α.
- IL-6.
- CRP.

The TNF-α and IL-6 in the serum were determined by enzyme linked immunosorbent assay (ELISA) kit as per the manufacturers' instruction while CRP was measured using routine automaton clinical chemistry techniques.

Pain and Patient Satisfaction

The severity of pain was measured using the 10-point Visual Analogue Scale (VAS) in which 0 indicated no pain and 10 indicated the most severe pain imaginable. Patient's satisfaction with the result of treatment was determined at the end of the treatment procedure using a satisfaction questionnaire, where a higher score meant larger satisfaction.

Outcome Measures

Primary Outcome

- The percentage of wound closure in twenty-eight days after the treatment.

Secondary Outcomes

- Indicating the change in TNF-α, IL-6 and CRP values.
- Reduction in pain.
- Change in local tissue perfusion.
- Frequency of wound healing.

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• Patient satisfaction.
• Adverse events related to treatment.

Statistical Analysis

For conducting the statistical analysis SPSS program was used to report continuous variables as the Mean ± SD (Standard deviation), while categorical variables were described in terms of frequencies and percentages. T test was used to compare variables between the two groups as well as within the groups. Chi-square test was used for the comparison of categorical variables. The association between percentage of wound closure and inflammatory markers was determined using the Pearson's test.

Ethical Considerations

Ethical approval was obtained from the Institutional Research Ethics Committee prior to the start of the study. Written informed consent was obtained from all participants prior to their enrollment. Confidentiality of participants was maintained, and the research procedures followed the ethical principles of Declaration of Helsinki and Good Clinical Practice.

Results

The total number of patients included in the study was 360 with 180 patients in the Low-Level Laser Therapy (LLLT) group and 180 in the control group. None of the patients were lost during the follow-up period, and all of them completed the treatment protocol. The baseline characteristics concerning demography and clinical characteristics were comparable in the two groups, which indicates that random sampling was successful.

Table 1. Baseline demographic and clinical characteristics of the study participants

Variable	LLLT Group (n = 180)	Control Group (n = 180)	*P*-value
Age (years)	43.7 ± 12.4	44.1 ± 11.8	0.781
Male, n (%)	98 (54.4)	95 (52.8)	0.764
Female, n (%)	82 (45.6)	85 (47.2)	0.764
BMI (kg/m^2)	26.8 ± 3.9	27.1 ± 4.1	0.532
Wound duration (days)	15.3 ± 5.2	15.8 ± 5.6	0.448
Baseline wound area (cm^2)	8.9 ± 2.4	9.1 ± 2.7	0.612
Baseline VAS pain score	7.1 ± 1.2	7.0 ± 1.1	0.587
TNF-α (pg/mL)	42.6 ± 8.1	43.1 ± 7.8	0.654
IL-6 (pg/mL)	31.4 ± 6.7	30.9 ± 6.4	0.573
CRP (mg/L)	12.1 ± 2.8	12.3 ± 2.6	0.692

As shown in **Table 1**, no statistically significant differences were observed between the study groups at baseline ($P > 0.05$), confirming that both groups were clinically comparable before treatment initiation.

Inflammatory Biomarkers

Inflammatory Biomarkers

After four weeks of treatment with Low-Level Laser Therapy, there was significant decrease in systemic inflammatory biomarkers.

Table 2. Changes in inflammatory biomarkers after treatment

Biomarker	Baseline	Week 4 (LLLT)	Week 4 (Control)	*P*-value
TNF-α (pg/mL)	42.6 ± 8.1	23.8 ± 5.9	36.5 ± 6.8	<0.001
IL-6 (pg/mL)	31.4 ± 6.7	17.2 ± 4.6	26.4 ± 5.3	<0.001
CRP (mg/L)	12.1 ± 2.8	4.8 ± 1.6	8.7 ± 2.1	<0.001

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As presented in **Table 2**, serum TNF-α, IL-6, and CRP concentrations were significantly reduced in the LLLT group compared with the control group. The greatest reduction was observed for CRP, which decreased by approximately 60% following laser treatment.

Clinical Outcomes

Pain intensity, tissue perfusion, and patient satisfaction were all improved significantly after the photobiomodulation was performed.

Table 3. Clinical outcomes following treatment

Variable	LLLT Group	Control Group	*P*-value
VAS pain score	2.4 ± 0.9	4.5 ± 1.2	<0.001
Tissue perfusion (%)	34.7 ± 5.1	12.8 ± 3.7	<0.001
Complete wound healing (%)	88.3	64.4	<0.001
Patient satisfaction (/10)	9.1 ± 0.6	7.2 ± 0.9	<0.001

As shown in **Table 3**, patients receiving Low-Level Laser Therapy experienced significantly lower pain scores, greater tissue perfusion, and higher complete wound-healing rates than those receiving standard wound care alone. Patient satisfaction was also significantly higher in the intervention group.

Correlation Analysis

Correlation analysis demonstrated a significant inverse association between inflammatory activity and wound healing.

Table 4. Pearson correlation between inflammatory biomarkers and wound closure

Variable	Correlation coefficient (r)	*P*-value
TNF-α	−0.67	<0.001
IL-6	−0.63	<0.001
CRP	−0.71	<0.001

As illustrated in **Table 4**, serum CRP concentration showed the strongest inverse correlation with wound closure percentage ($r = -0.71$, $P < 0.001$). Similar negative correlations were identified for TNF-α and IL-6, indicating that reduced inflammatory activity was associated with accelerated tissue regeneration.

Summary of Findings

In summary, it can be stated that Low-Level Laser Treatment noticeably improved the wound-healing process, decreased the systemic inflammatory markers, enhanced the delivery of blood to the tissue in the affected area, eased the level of pain felt by the patients and increased their overall satisfaction with the treatment according to the traditional wound care. No major adverse treatment-related events have been registered during the course of the study.

Discussion

The current study has shown that LLLT improves wound healing, decreases concentrations of inflammatory markers, increases local tissue blood circulation, decreases pain, and enhances patient satisfaction when used in combination with standard wound treatment. Thus, the aforementioned findings give additional support to future studies which demonstrate that photobiomodulation promotes tissue healing by affecting inflammatory processes and stimulating cell regeneration.

One of the most important observations during this study was that patients receiving LLLT demonstrated a considerably higher wound closing rate. The experimental group underwent epithelial restoration and tissue repair faster than the control group throughout the study, which indicates that laser treatment is effective in boosting biological processes related to wound healing.

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These findings correlate with previous studies showing photobiomodulation as an agent stimulating fibroblast proliferation, collagen production, angiogenesis, and remodeling of connective tissue, which contribute to faster closure of wounds (6–9). De Freitas and Hamblin (7) stated that laser photons are captured by mitochondrial cytochrome c oxidase which then leads to production of ATP and beginning of synthesis of signals involved in cell proliferation and migration. The authors Dompe et al. (9) summarized that photobiomodulation facilitates the regenerative processes through improvement of cellular metabolism and vascularization.

The current study found significant decreases in TNF-α, IL-6, and CRP levels in serum after laser treatment. These results imply that the positive clinical effects coincided with the decrease in systemic inflammation. The continuous elevation of pro-inflammatory markers hampers the transition from the inflammatory phase to the proliferation stage of wound healing (2,3). The findings of the current study concerning the anti-inflammatory properties are consistent with the findings of Hamblin (8) who showed that photobiomodulation inhibits the production of inflammatory cytokines while increasing tissue restoration through the adjustment of oxidative stress and immune cell behavior. In addition, Gavish and Houreld (6) concluded that photobiomodulation creates a conducive microenvironment for healing injuries by decreasing inflammation while promoting angiogenesis.

The decrease in inflammation markers that was registered in the present paper is in line with the research carried out by our team. Hadi et al. (11)

According to findings by Hadi et al. (12), inhibition of inflammatory processes effectively decreased the extent of tissue injury during myocardial ischemia-reperfusion. Although Hadi et al. (12) emphasized the contribution of NF-κB signaling pathway activation to inflammatory tissue damage and oxidative stress, the decrease in TNF-α and IL-6 levels found in this study indicates that suppression of inflammatory processes could be characteristic of cutaneous wound healing as well.

Although these earlier findings were based on cardiovascular tissues and not cutaneous wounds, the inflammatory mechanisms involved are likely to be similar in both cases. In this study, the most important result was represented by the increased perfusion of tissues along with the substantial reduction of pain perception. Increased microcirculation as a result of laser therapy facilitates enhanced delivery of oxygen, nutrients, and removal of waste products, thereby creating favorable conditions for tissue repair, meanwhile improved perfusion helps fibroblasts work more efficiently and deposit collagen. Comparable results have been obtained in the previous studies investigating the impact of photobiomodulation on local blood flow through vasodilatation due to nitric oxide release and activation of mitochondria (7–9).

The correlation analysis also revealed significant negative relationships between inflammatory markers and wound healing rates, with CRP showing the strongest level of association. This study may provide some evidence that patients with lower inflammation are able to heal faster and regenerate tissues more rapidly. The results align with findings by Sadiq et al. (13), where C-reactive protein was established as a good marker of inflammation levels and severity of the disease. Although the authors of the study focused on inflammatory complications during pregnancy, the authors showed good validation of CRP as a systemic inflammation marker, confirming its potential for the monitoring of patients during wound healing.

Patients reported much higher satisfaction after having undergone photobiomodulation therapy. This observation provides us with clinically significant findings, since patients' feedback is becoming an increasingly important tool for assessing treatment outcomes. Our findings also resemble the results obtained by Yousif et al. (14), where patients receiving stem cell therapy were found to experience better healing outcomes. Although both methods are different in terms of their biological mechanisms, they have similar intention of improving tissue regeneration.

Some of the strengths of the present study are its prospective randomised controlled design, relatively large sample size, provision for assessment of laboratory and clinical outcomes, and incorporation of objective inflammation markers into non-invasive biophysical assessment. Inclusion of wound healing process, inflammation markers, tissue perfusion, and patients' feedback about their condition provides for overall assessment of treatment effectiveness and adds clinical importance to the results obtained.

However, there are a number of limitations that need to be addressed. First of all, it should be noted that this study was conducted in one clinic, which limits the possibility of generalisation of the resulted findings. Secondly, only one wave length and irradiation protocol were evaluated and therefore, it is impossible to determine the parameters of the optimal treatment. Third, the follow-

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up period was limited to four weeks which prevented the assessment of long-term scarring and recurrence of the problem. Finally, other biomarkers such as vascular endothelial growth factor (VEGF), transforming growth factor beta (TGF-β), matrix metalloproteinases (MMPs) and markers of oxidative stress should have been tested in this case as well.

In summary, the results of the study corroborate the concept that Low-Level Laser Treatment is both safe and efficacious as a co-adjunctive intervention. By helping in faster wound closure, reduction of inflammatory responses, enhancement of tissue blood flow and improvement in satisfaction levels of the patients' photobiomodulation represents a potentially effective way to improve the management of wounds. Therefore, it is important to conduct a multicentre randomized study with extended follow-ups and molecular examination in order to develop standardized treatment protocols.

Conclusion

Low-Level Laser Therapy (LLLT) has been shown to significantly improve the healing of wounds by speeding up their healing process, diminishing the levels of inflammation indicators in the blood, enhancing blood supply to tissues, relieving pain, and improving patients' quality of life compared to traditional wound care. The decrease of TNF-α, IL-6, CRP has shown that the changes in the immune response are the leading mechanism of the photobiomodulation effect during restoration. In addition, the close negative dependence between inflammation indicators and wound healing means the significance of eliminating inflammation during the process of recovery.

In general, it may be concluded that LLLT is a secure and useful method used to treat wounds of skin level, which may be considered a supplement to traditional methods of treatment. Further multicenter controlled randomized trials with larger number of patients, longer observation period, and molecular tests should be carried out in order to improve the laser treatment scheme and better understand the mechanisms of photobiomodulation.

References

1. Sen CK. Human wounds and its burden: an updated compendium of estimates. Adv Wound Care (New Rochelle). 2019;8(2):39–48.
2. Rodrigues M, Kosaric N, Bonham CA, Gurtner GC. Wound healing: a cellular perspective. Physiol Rev. 2019;99(1):665–706.
3. Eming SA, Wynn TA, Martin P. Inflammation and metabolism in tissue repair and regeneration. Science. 2017;356(6342):1026–1030.
4. Landén NX, Li D, Ståhle M. Transition from inflammation to proliferation: a critical step during wound healing. Cell Mol Life Sci. 2016;73:3861–3885.
5. Guo S, Dipietro LA. Factors affecting wound healing. J Dent Res. 2010;89(3):219–229.
6. Gavish L, Houreld NN. Photobiomodulation therapy for wound healing and skin regeneration. Adv Skin Wound Care. 2019;32(8):361–364.
7. de Freitas LF, Hamblin MR. Proposed mechanisms of photobiomodulation or low-level light therapy. IEEE J Sel Top Quantum Electron. 2016;22(3):7000417.
8. Hamblin MR. Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. AIMS Biophys. 2017;4(3):337–361.
9. Dompe C, Moncrieff L, Matys J, et al. Photobiomodulation—Underlying mechanisms and clinical applications. J Clin Med. 2020;9(6):1724.
10. Aggarwal I, Lio PA. Photobiomodulation therapy and low-level light therapy in wound healing. Lasers Med Sci. 2023;38:239.
11. Hadi NR, Al-Amran FGY, Yousif MG, Hussein FH. Amelioration of myocardial ischaemia/reperfusion injury by L-carnitine via down-regulation of the inflammatory response and apoptosis. Exp Clin Cardiol. 2014;20(8):3732–3740.
12. Hadi NR, Yousif NG, Abdulzahra MS, Majeed ML, Yousif MG. Role of NF-κB and oxidative pathways in atherosclerosis: cross-talk between dyslipidaemia and candesartan. Cardiovasc Ther. 2013;31(6):381–387.
13. Sadiq AM, Hussein CM, Yousif MG, Mohammed RJ. Correlation between highly sensitive C-reactive protein level in cases of preeclampsia with or without intrauterine growth restriction. Indian J Forensic Med Toxicol. 2020;14(4):6012–6016.
14. Yousif NG, Yousif MG, Mohsen AH, Nöth UA, Hassan AM. Prospective single-centre analysis of outcome stem cell transplants in patients with cerebral palsy. Pol Merkur Lekarski. 2023;51(4):339–345.
15. Eming SA, Wynn TA, Martin P. Inflammation and metabolism in tissue repair and regeneration. Science. 2017;356(6342):1026–1030.

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