POLARIZED LIGHT VERSUS LIGHT-EMITTING DIODE ON HEALING OF CHRONIC DIABETIC FOOT ULCER

HEBA BAHEY EL-DEEN, SEHAM FAHMY**, S.A. ALI***[#], W.M. EL-SAYED*****

*Faculty of Physical Therapy, Misr University for Science and Technology, Giza, Egypt
**Department of Physical Therapy, Kobri El Koba Military Hospital, Cairo, Egypt
***Center of Basic Sciences (CBS), Misr University for Science and Technology, Giza, Egypt,
On leave from the Department of Biophysics, Faculty of Science, Cairo University, Giza, Egypt,
[#]e-mail: saidtaha@aucegypt.edu
****General Surgery Department, Kobri El Koba Military Hospital, Cairo, Egypt

Abstract. Background: Phototherapy is characterized by its ability to induce photobiologicalprocesses in both cellular and subcellular levels. Many studies and researches have recommended the successful application of light therapy in the management of diabetic foot ulcer, acceleration of healing rate and recovery to overcome this serious problem. Purpose: The purpose of this study was to compare between the effects of polarized light therapy and light-emitting diode therapy on diabetic foot ulcer. Subjects and Methods: Thirty patients of both sexes with type 2 diabetic foot ulcers participated in this study. The mean values of their ages were 59.1±7.68 and 60.9±8.3 years respectively. They were classified into two equal groups (15 patients each) PL group received polarized light therapy and LED group received non polarized light-emitting diode therapy three times per week for two months. Both groups received traditional medical treatment in addition to light therapy. Wound surface area and depth were calculated for all participated patients. These measures were recorded three times during the period of the study; before treatment, after 1 month and at the end of the study period, after two months. Results: The results of this study showed significant reduction of surface area and depth of ulcer in both groups at the end of the study period with higher improvement in favor of polarized light group. Conclusion: It was concluded that, polarized light therapy seems to be more effective in accelerating healing of grade II diabetic foot ulcer than light-emitting diode therapy.

Key words: Light-emitting diode therapy, polarized light therapy, diabetic foot ulcer.

INTRODUCTION

Foot complications are remaining a source of mortality in diabetic patients and contributing to increased healthcare costs, higher rates of work time lost and disability [4].

Received: June 2014;
in final form August 2014.

ROMANIAN J. BIOPHYS., Vol. 24, No. 2, P. 000–000, BUCHAREST, 2014

In these populations, peripheral neuropathy and arterial disease (PAD) are predisposed to foot ulceration and infection which may cause more than 66% of lower-limb amputation and wound healing failure. Despite the reduction in amputation rates for people suffering from diabetes, they are still considered high when compared to non-diabetic rates [3]. This emphasized the importance of searching successful treatment of diabetic foot ulcers [14].

Many previous reports have been conducted to investigate different effects of several types of phototherapies on the treatment of chronic wound healing such as low level laser, ultraviolet, monochromatic infrared, light-emitting diode and polarized light therapy [30].

Polarized phototherapy is a relatively new therapeutic approach. In this technique a linearly polarized, polychromatic light was used where the light waves move in parallel planes, producing a narrow, concentrated beam. Unlike ordinary light where its waves oscillate in all directions, polarized light comes from refraction of common light through special laminated mirrors to be passed through a photo filter system [28].

Polarized light had positive biological effects for enhancement of the cell membrane functions, increasing the rate of adenosine triphosphate production (ATP) in mitochondria. Moreover, it reduced inflammation; enhanced microcirculation, tissue oxygenation, fibroblast proliferation, composition of collagen and accelerated epithelialization. As a result of improving these functions, this approach was promising to enhance wound healing process [27].

Since its early development in the late 1990s, light-emitting diodes LED has been used by NASA for acceleration of wound healing [39]. The effectiveness of LED therapy stemmed from its efficacy at a cellular and subcellular level especially for 633 nm and 830 nm wavelengths. Moreover, using 830 nm wavelengths enhanced blood flow and it was attributed to neovascularization. Clinical implementation of LED phototherapy helps non-healing wounds to be healed through restoring collagenesis/collagenase imbalance while normal wound was found to heal faster and better [26].

It was also found that LED phototherapy can reduce pain, postoperative edema and many other types of inflammation [15]. Researchers showed that the application of LED therapeutic devices can be arranged in large; flat arrays and produce multiple wavelengths allowing treatment of wounds with large surface areas [21].

The present study was designed to compare the influence of polarized light therapy versus light-emitting diode therapy on enhancement of healing of chronic diabetic foot ulcer and to determine which one was better and faster.

MATERIALS AND METHODS

PATIENTS

Thirty diabetic patients from both sexes (14 females & 16 males) with grade II foot ulcer (according to University of Texas classification) [2, 19] with duration ranged from 1 to 3 months participated in this study. They were referred from vascular and general surgery out-clinics in Kobri El-Koba Military Hospital. Their ages ranged between 48–72 years. Patients were randomly classified into two groups of equal number by one to one way: The polarized light group (PL group, 15 patients) received polarized light therapy and the light-emitting diode group (LED group, 15 patients) received LED therapy. Patients in the two groups received the same medical treatment and controlled diet described by their physician and they had controlled blood glucose level. Patients with any disorder which lead to ulcer other than diabetes were excluded from the study e.g. varicose veins, trauma, and other skin diseases. The present study was approved by Faculty of Physical Therapy, Misr University for Science and Technology. All participants were informed about the nature and the effects of the trial and were instructed to report any side effects during the treatment sessions. They assigned an informed consent to participate in the study. Evaluation and treatment procedures were accomplished in the Physical Therapy Department in Kobri El-Koba Military Hospital.

INSTRUMENTATIONS AND PROCEDURES

For evaluation

Wound surface area and depth measurements were done in a standardized manner at the beginning of the study, after one month and at the end of the two months. Each ulcer was graded using University of Texas (TU) system to assess ulcer depth, the presence of wound infection, and the presence of clinical signs of lower-extremity ischemia. Physical examination was performed on patients, including palpation of the arterial pulses to identify lower-extremity vascular insufficiency on the basis of absence of both pedal pulses of the involved foot and/or an ankle-brachial pressure index of < 0.9 [8].

Measurement of ulcer size

Wound tracings were accomplished by outlining the wound circumference onto a double layered transparency metric grid of 16 × 16 squares (1 cm^2 each)

model sheet applied directly over the wound and fine tip permanent marker to trace wound perimeter within the grid area. The transparency layer in contact with the wound was sterilized to eliminate the possibility of contamination and then it was discarded. The transparency model sheet was scanned using HP LaserJet M1005 MFP equipped with a scanner. The scanned wound was saved and opened as image on a personal computer using Adobe Photoshop CS6 program. The scanned wound was then processed where the pixel value (pixels number within WSA outline) was calculated. The number of pixels in the 1 cm^2 standard unit areas in the transparency grid was calculated too. Then the number of pixels in the outlined wound was divided by the number of pixels in the standard unit area to get the wound area in square centimeters [21]. Using the ulcer surface we defined two parameters to quantitatively follow the treatment efficiency. First is the percent of change of ulcer surface area defined as the decrease in the ulcer surface area as a percent of the initial area. The second is the rate of change of ulcer surface area defined as the percent of change divided by the number of weeks of treatment to get the change per week.

Measurement of ulcer volume

Patient was reclined in a supine position to allow complete filling of the ulcer against gravity. An adhesive transparent sheet was applied tightly over the ulcer. A 5 cm^3 syringe with removed needle was filled with normal isotonic saline solution. The ulcer was injected with saline maximally to measure ulcer volume where the volume of solution needed to fill the ulcer was recorded [1].

In order to improve the accuracy of tracings and measuring volume, each procedure was performed 3 times and the mean was calculated. The same clinician performed all wound tracings and volume measurements. Evaluation process was conducted in a double blind manner where all participated patients and clinicians (who performed the evaluations procedures) were unaware whether experimental subjects belonging to which experimental group either polarized light group or light-emitting diode group. Using the ulcer volume we defined two parameters to quantitatively follow the treatment efficiency. First is the percent of change of ulcer volume defined as the decrease in the ulcer volume as a percent of the initial volume. The second is the rate of change of ulcer volume defined as the percent of change divided by the number of weeks of treatment to get the change per week.

For treatment

For all patients recruited in the study, dressings were removed, wounds were cleaned of foreign debris or dressing residue and the ulcer was irrigated with normal saline prior to application. If any patient felt pain during treatment, irradiation was ceased immediately.

Polarized light therapy group (PL group)

Bioptron Pro 1 Class II, (Bioptron AG, Wollerau, Switzerland) device with floor stand emitted polarized light lamp with wavelengths ranged from 480–3400 nm was used in this study (Fig. 1).

Fig. 1. Bioptron Pro 1 Class II Device.

The Bioptron Light Therapy System is a medical light therapy device with a specific optical unit emitting light that is similar to a part of the electromagnetic spectrum produced naturally by the sun but with no UV radiation. The Bioptron Light Therapy System is a powerful light therapy technology demonstrating a remarkable degree of visionary commitment. In the early 1980s, a team of scientists discovered the significance of polarized polychromatic light. Based on this research, the Bioptron Light Therapy System was created [25].

The Bioptron Light Therapy System is designed and manufactured in such a way that the light emitted by this medical device can be characterized as: 1) polarized light, its waves move (oscillate) on parallel planes, 2) encompasses a wide bandwidth. The wavelength ranges from 480 nm to 3400 nm, 3) incoherent or "out-of-phase" light, 4) a low energy density, reaching the area to be treated with a constant, steady intensity. This energy density has biostimulative effects [11, 12, 34]. When applied to the skin, it stimulates light-sensitive intracellular structures and biomolecules. This initiates cellular chain reactions and triggers so-called secondary responses, which are not only limited to the treated skin area but can involve the whole body.

During the treatment, the head of the device was directed perpendicular to the ulcer area with a distance of 10 cm. The degree of polarization was > 95%. Its specific power density was approximately 40 mW/cm^2. This was equivalent to an energy density (fluence) of an average of 2.4 J/cm^2 per minute (Fig. 2).

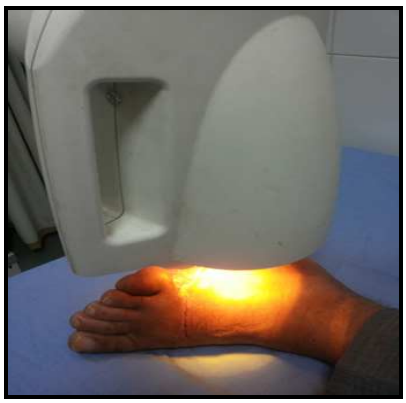
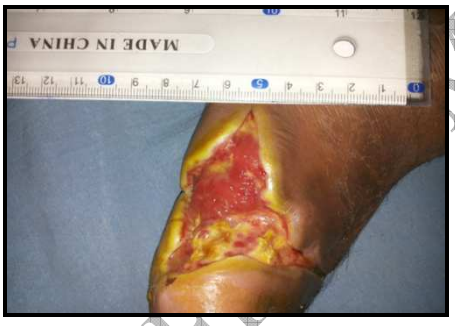


Fig. 2. Application of polarized therapy.

Duration of each session was 8 min. The frequency of treatment was 3 times per week day after day for a total of consecutive 8 weeks. The ulcer before polarized light therapy, Fig. 3a and the ulcer after 2 months of polarized light therapy, Fig. 3b are shown.

a. 

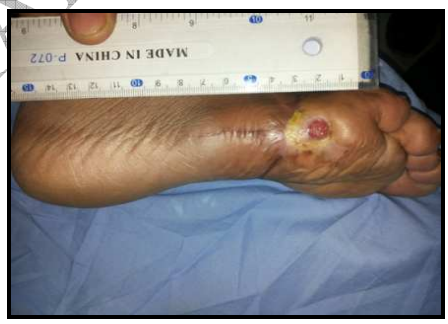
b. 

Fig. 3. a. The ulcer before polarized therapy; b. the ulcer after 2 months of polarized therapy.

Light-emitting diode therapy group (LED group)

LED device (Vectra Genisys laser n. 27808, Chattanooga group of encore medical, Texas, USA), Fig. 4 was applied in contact with the wound using cling film as isolator between the LED head and the ulcer site, Fig. 5.

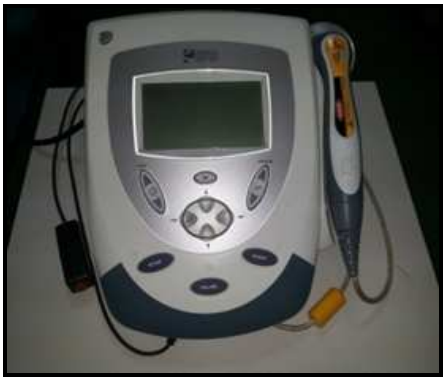


Fig. 4. LED device.

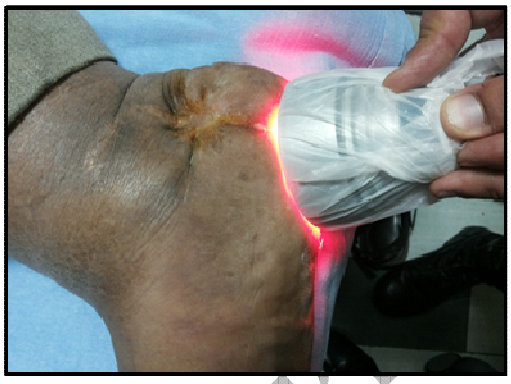
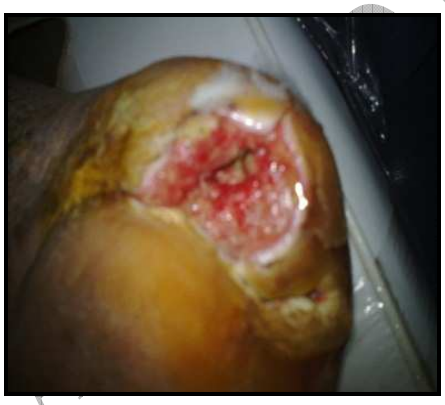


Fig. 5. Application of LED therapy.

Therapist and patient put on goggles to protect their eyes. LED treatment was given by 33 diode cluster applicator, which were arranged to produce total power output 1440 mW with following wave lengths: 5 × 850 nm 200 mW lasers, 12 × 670 nm 10 mW LED, 8 × 880 nm 25 mW LED, 8 × 950 nm 15 mW LED and energy density (fluence) was adjusted for 4 J/cm^2 with pulse frequency of 10 KHz. Each session lasted 8 minutes for 3 times per week day after day for a total of consecutive 8 weeks. The ulcer before LED therapy and the ulcer after 2 months of LED therapy are shown in Fig. 6 a and b, respectively.

a. 

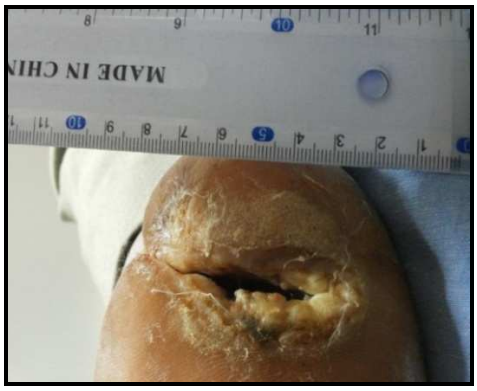
b. 

Fig. 6. a. The ulcer before LED therapy; b. The ulcer after 2 months of LED therapy.

STATISTICAL ANALYSIS

The independent t-test was used to compare the results of LED and PL groups concerning the percentage of change (%) of ulcer surface area (*PCUSA*),

the rate of change of ulcer surface area (*RCUSA*), the percentage change (%) of ulcer depth (*PCUD*) and the rate of change of ulcer depth (*RCUD*) before, after one month and at the end of the study, after two months. The program SPSS version 16 was used in statistical analysis.

RESULTS

Before starting the PL and LED treatments, an evaluation of the patients group have been done. The data illustrated in Table 1 revealed non-significant difference between PL and LED groups before conduction of the study regarding to the patients' ages, duration of diabetes, duration of ulcers, initial ulcer surface area and initial ulcer depth.

Table 1

Initial subjects and ulcer criteria in both groups

Variables	PL group $X' \pm SD$	LED group $X' \pm SD$	Mean diff. $\pm SD$	*P*-value
Age (year)	60.9±8.3	59.1±7.68	1.86±2.93	>0.05
DDM (year)	16.1±3.4	16±4.4	0.13±1.4	>0.05
DU (month)	3.3±1.3	3.5±1.7	0.2±0.48	>0.05
IUSA (cm^2)	3±1.3	3.3±1.2	0.3±0.47	>0.05
IUD (cm^3)	2.4±2	2.6±1.8	0.2±0.31	>0.05

$X' \pm SD$: mean ± standard deviation, *DDM*: duration of diabetes mellitus, *DU*: duration of ulcer, *IUSA*: initial ulcer surface area, *IUD*: initial ulcer depth, level of significance: $P = 0.05$.

The mean values of initial criteria in both groups are presented in Fig. 7.

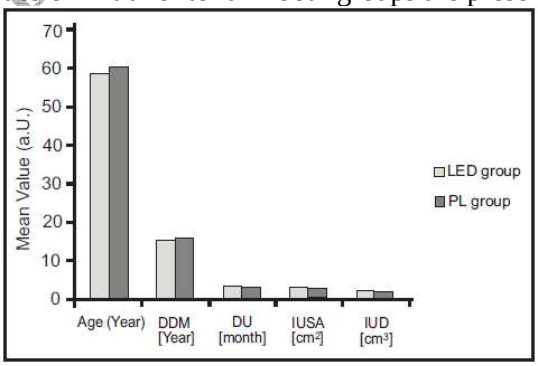


Fig. 7. Mean values of initial criteria in both groups.

POLARIZED LIGHT THERAPY GROUP

The statistical analysis of data of both groups per week in the first month is shown in Table 2. Clear statistically significant differences have been revealed between the LED and PL groups for all of the investigated parameters.

Table 2

Ulcer parameters after one month in both groups

Variables	LED group $X' \pm SD$	PL group $X' \pm SD$	Mean diff. $\pm SD$	*P*-value
PCUSA (%)	34.04±0.98	55.05±23.45	21.01±8.12	<0.05
RCUSA (%/week)	8.51±1.759	13.76±6.0	5.25±2.06	<0.05
PCUD (%)	42.96±12.8	56.7±21.46	13.74±6.45	<0.05
RCUD (%/week)	10.74±3.5	14.17±6.02	3.43±1.25	<0.05

The mean values of ulcer parameters after one month in both groups are presented in Fig. 8.

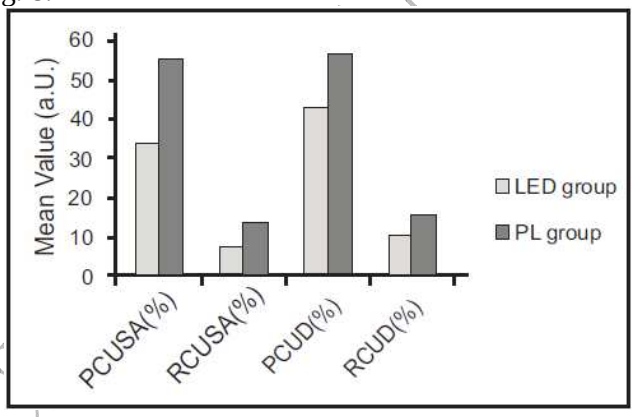


Fig. 8. Means of ulcer parameters after one month in both groups.

LED THERAPY GROUP

The statistical analysis of data of both groups after two months which showed a better improvement in the results is shown in Table 3. It was also observed that 5 of the fifteen (33.3%) patients had complete healing at the end of the study period after two months.

Table 3

Ulcer parameters after two months in both groups

Variables	LED group *X'*±*SD*	PL group *X'*±*SD*	Mean diff. ±*SD*	*P*-value
PCUSA (%)	59.28±12.8	77.3±21.46	18.02±8.6	<0.05
RCUSA (%/week)	7.41±3.15	9.66±2.77	2.25±1.1	<0.05
PCUD (%)	76.35±11.58	82.08±18.31	5.73±5.6	>0.05
RCUD (%/week)	9.54±2	10.26±2.37	0.72±0.15	>0.05

The Mean values of ulcer parameters after two months in both groups are presented in Fig. 9.

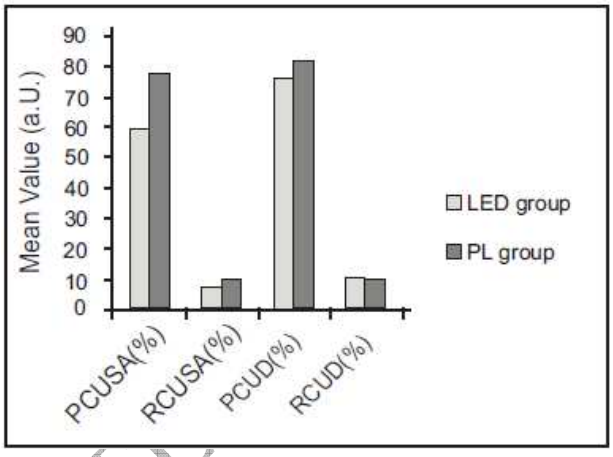


Fig. 9. Mean values of ulcer parameters after two months in both groups.

DISCUSSION

The current study was conducted on chronic diabetic foot ulcer that lasted from 1 to 3 months. This was carried out to get the most beneficial effect of phototherapy that depends on the physiological state of the cell at the moment of irradiation. This comes in agreement with the study of [35], who stated that, at the time of irradiation, light can stimulate cell proliferation especially in cases with poor cellular growing rate such as in chronic wounds.

In an *in vivo* study performed by T.N. Demidova-Rice *et al.* [5] used a set of fluences of 1, 2, 10 and 50 J/cm^2 delivered at constant rate of 100 mW/cm^2 of light delivered from a filtered lamp with wavelength of 635 nm. This study was conducted on a full thickness dorsal excisional wound in mice treated with a single

exposure to light 30 minutes after wounding. They proved that positive effects of wound size were observed in low doses with maximum response at 2 J/cm^2 than high doses of 50 J/cm^2 which gave a worsening effect of the wound healing time. From the previously mentioned results, the present study used a fluence equal 2.4 J/cm^2 which was within this range of lower doses.

Different tissues and cells in the body have unique light absorption characteristics (optical properties), that produce a maximum therapeutic effect. This optical window runs approximately from 650 nm to 1200 nm showing different positive changes at a cellular level. The photons of light must be absorbed by electronic absorption bands belonging to some molecular photoacceptors, or chromophores [36]. The action spectrum showed which specific wavelength of light was most effectively used in a specific chemical reaction [13]. This is why the polarized light used in the present study had combined several infrared and visible light wavelengths in one unit that ranged from 480 nm to 3400 nm and did not contain harmful effects of ultraviolet light.

It has gradually become obvious that no single wavelength can accomplish all required reactions in the wound healing process, whereas combinations have proved significantly more effective [37]. Furthermore, wavelengths of less than 630 nm such as yellow, blue and green are considerably blocked by the hemoglobin in the blood, so they do not penetrate deeply [23], while wavelength of 830 nm can enhance the stimulatory effect of the activated keratinocytes in the epidermis. In addition, epidermal cells have been proven to respond well to low levels of visible light energy through enhanced mitochondrial activity [26]. These results agreed with the current study which has been used combinations of different wave lengths simultaneously. In the present study LED system used 4 wave lengths 850 nm lasers, 670 nm, 880 nm and 950 nm. This may be contributed with the evidence that a wavelength provide better biological response than another. S. Roberts [31] indicated that 620, 680, 760, and 820 nm could be the most appropriate wavelengths for health treatments. While M.C. Moreira *et al.* [29] reported that LEDs that are commercially available emitted light in some certain wavelengths such as 630, 660, 850, and 880 nm showed excellent wound healing characteristics acting to subcutaneous tissues

Significant acceleration of the healing was observed in the PL therapy group, among 15 patients who underwent 20 sessions of PL therapy, eight of them (53.33%) had completely healed ulcers after 8 weeks of the study period. Comparison of statistical analysis of all measuring values in both groups after one month revealed highly significant improvement in all measured parameters in response to PL therapy.

These results come in agreement with S. Monstrey *et al.* [28], who proved that daily Bioptron polarized therapy accelerated wound closure in 22 patients with deep second degree burns, significantly shortened healing time, reduced scarring

and optimized long-term functional results. Moreover, A. Simic *et al.* [33] compared Bioptron therapy to the standard care regime of 26 patients who had underwent total gastrectomy leaving left thoracophrenolaparotomy wounds with a mean length of 42 cm on the chest and abdomen. Outcomes were significantly better in the Bioptron group on the 12^{th} postoperative day**.** Furthermore, P. Iordanou *et al.* [10] examined the effect of Bioptron therapy on 55 in-patients with pressure ulcers in addition to standard care. Statistically significant differences were observed at the end of week one and two between treated and untreated ulcers. Ulcers in the treated group had shrunk in size by a mean 10.56% versus 0.95% in the control group.

The results also come in agreement with a study conducted by L. Medenica, M. Lens [24] who assessed the effectiveness of polarized, polychromatic, non-coherent light therapy in the treatment of venous leg ulcers. Phototherapy treatment was given once a day over four weeks. All ulcers of total 73 ulcers except one had a positive value through the change in healing rate and the decrease in wound surface area.

The achieved results of the current study may be attributed to previous reports performed by P. Iordanou *et al.***,** S. Monstrey *et al.***,** A.L. Pinheiro *et al.***,** [10, 27, 30] who suggested that polarization was the responsible for the bio modulation of biological systems. It has a low energy density, reaching the area to be treated with a constant, steady intensity. Additionally, polarized light has no single mechanism of action. N. Lane [18] proposed that low level light might work on photo-dissociating nitric oxide (NO) from cytochrome oxidase (Cox) and thus may increase the respiration rate by reversing the mitochondrial inhibition of respiratory chain due to excessive NO binding.

A.L. Pinheiro *et al.* [30] study indicated that the use of 685 nm of polarized light with a dose of 20 J/cm^2 resulted in increased collagen deposition and better organization on healing wounds, and that the number of myofibroblasts were increased when polarized light was used. M.A. Trelles *et al.*, M.R. Watson *et al.*, [37, 38] also proved that fibroblasts in the edge of the wounded dermis can be transformed into myofibroblasts and the contractile nature of these cells with their smooth muscle actin fibers preventing wound expansion. This may come in agreement with the results of the current study which showed higher improvement in wound surface area and its rate per week in the first month and consequently better improvement was achieved in response to PL per week at the end of the second month.

Polarized light also stimulated self-defense mechanisms of the body. Microscopic studies proved that following polarized light therapy, the number of white blood cells such as lymphocytes, monocytes, and eosinophilic cells significantly increased [6, 7]. The stimulating effect of the polarized light on the immune system was repeatedly proven in laboratory tests *in vitro*, it was shown

that polarized light stimulated the activity of T-lymphocytes in the blood [16]. It has also been proved that polarized light stabilized the cell membrane of erythrocytes that bind more oxygen molecules and transferred them to each organ and cell of the body.

The current study used non-coherent light in both types of phototherapy either with polarized light or light-emitting diode. This comes in agreement with A.N. Rubinov [32] whore ported that the primary interaction of light with biological matter is purely photochemical in nature where the absorption of light through some photoreceptors starts a chain of biochemical reactions and in this case coherence of light is not important. In deed high coherence of light i.e. (when the phase of oscillations in electromagnetic wave remains unchanged for a long time) may be important if the phase of electron oscillations in the excited substance by light is also kept unchanged long enough. This is not true in bio-molecules which contained tremendous number of atoms in which their interaction with each other leads to rapid change of electron oscillations phase. Moreover, M.A. Trelles *et al.* [37] suggested that refraction and reflection of light was intense in organic substrates. This process is responsible for the dispersion of light suggesting that coherence in photo therapy has relevance when dealing with deep targets as joints and muscles. While for superficial targets as in skin wounds, coherence loses a lot of its importance.

According to our results, LED based therapy proved to be less efficient than the PL therapy. After one month the relative decrease of ulcer surface for LED group was ~ 0.6 of the value measured in the PL group. In the case of ulcer depth, the relative decrease in the LED group was ~ 0.75 of the value measured in the PL group. Similarly, the rates of healing were higher in the PL group, the differences being statistically significant. This may be attributed to what was proved by W.S. Kim and R.G. Calderhead [15] who reported that light-emitting diodes had low and unstable output powers, high angles of divergence with poor photon intensities and lack of wavelength specificity. They also added that it was easy to find an emitted red LED with a waveband ranges from 600 to 680 nm but almost impossible to find LED with specific 633 nm. However skin cells maintained a good interaction with LED. Even with much more expensive superluminescent LEDs (sLEDs) were significantly less effective in inducing neovascularization in a rat model compared with a laser diode at the same 830 nm wavelength and similar dose [17]. However the systemic effect of 830 nm LED phototherapy was proved to accelerate wound healing in indirectly-irradiated dorsal wounds in an animal model [19].

By the end of the second month, the results showed non-statistically significant difference, the values of healing parameters for the PL group being closer to those of LED group, but still higher. This may be attributed to the small sample size of participated patients in this study. Significant difference may be observed with larger sample. This non-statistically significant difference may also

be attributed to individual variations of tissue response to the light therapy and to the healing rate which was faster in the first month than in the second month.

L. Hode, J. Tunér [9] reported that the non-coherent light was useful therapy but less efficient than coherent light such as laser therapy and probably non-coherent light is most efficient on superficial structures than deeper ones. They also added that the coherence was lost when laser light was scattered in tissue while those authors showed by an experiment that the coherence of laser was not lost by tissue due to scattering.

Polarization has also been suggested as important factor on tissue absorption and responses [15]. Polarization may produce nearly 80% of the effects of laser light but non polarized light may not. The degree of polarization decreases directly with tissue depth thus polarized light produce its effects on more superficial tissues leading to more epithelialization and local peripheral vasodilatation enhancing blood flow of the skin and delivery of oxygen to wounded area.

Polarized light is an electromagnetic wave that is oscillating in a specified one plane that interacts with the electrons and protons in the respiratory chain more efficiently than un-polarized light which is oscillating in all directions. Additionally, the polarized light seems to enhance important biochemical processes involved in the absorption, resonant and non-resonant scattering phenomena when it passes through the tissues.

CONCLUSION

It can be concluded that, patients in both groups showed improvement in healing of their foot ulcers at the end of the study, after two months of treatment. Both polarized light therapy and light-emitting diode therapy can be considered a valuable therapy for the treatment of various wounds and wound healing disorders. They can promote and speed up wound healing through the stimulation and modulation of regenerative processes, anti-inflammatory effects and enhancing processes of the human defense system. However, polarized light therapy seems to be more effective in accelerating the healing rate and shortening hospitalization time than LED therapy.

Acknowledgements. We thank Prof. Dr. Hala Kassem, the dean of the faculty of Physical Therapy, Misr University for Science and Technology for her support and critical revision of the manuscript.

REFERENCES

1. BOULTON, A.J., The diabetic foot: a global view, *Diabetes Metab. Res. Rev.*, 2000, **16**, S2–S5.

2. BOULTON, A.J., The diabetic foot, *Medicine*, 2006, **34**(3), 87–90.
3. BOWERING, K., J. EMBIL, Clinical practice guide lines foot care, *Can. J. Diabetes*, 2013, **37**, S145–S149.
4. BREM, H., P. SHEEHAN, H. J. ROSENBERG, J. SCHNEIDER, A. BOULTON, Evidence-based protocol for diabetic foot ulcer, *Plast. Reconstr. Surg.*, 2006, **117**, 193S–209S.
5. DEMIDOVA-RICE, T.N., E.V. SALOMATINA, A.N. YAROSLAVSKY, I.M. HERMAN, M.R. HAMBLIN, Low-level light stimulates excisional wound healing in mice, *Lasers Surg. Med.*, 2007, **39**, 706–715.
6. FENYO, M., Theoretical and experimental basis of biostimulation, *Opt. Laser Technol.*, 1984, **16**, 209–215.
7. FENYO, M., J. MANDL, A. FALUS, Opposite effect of linearly polarized light on biosynthesis of interleukin-6 in a human B lymphoid cell line and peripheral human monocytes, *Cell Biol. Int.*, 2002**, 26**, 265–269.
8. FRYKBERG, R.G., D.G. ARMSTRONG, J. GIURINI, Diabetic foot disorders: a clinical practice guideline, *J Foot Ankle Surg.*, 2000**, 39**, S1–60.
9. HODE, L., J. TUNÉR, Low level laser therapy (LLLT) contra light-emitting diode therapy (LEDT) – what is the difference?, In: *Laser Florence 99: A Window On The Laser Medicine World*, L. Longo, A.G. Hofstteter, M.L. Pascu, W.L. Waidelich, eds, 2000, Proceedings of SPIE, **4166**, pp. 90–97.
10. IORDANOU, P., G. BALTOPOULOS, M. GIANNAKOPOULOU, P. BELLOU, E. KTENAS, Effect of polarized light in the healing process of pressure ulcers, *Int. J. Nurs. Practice*, 2002, **8**, 49–55.
11. KARU, T., Molecular mechanism of therapeutic effect of low-intensity irradiation, *Laser Life Sci*, 1988, **2**, 63–71.
12. KARU, T., Primary and secondary mechanisms of action of visible to near-IR radiation on cells, *J. Photochem. Photobiol.*, 1999, **49**, 1–17.
13. KARU, T.I., S.F. KOLYAKOV, Exact action spectra for cellular responses relevant to phototherapy, *Photomed. Laser Surg.*, 2005, **23**, 355–361.
14. KAWALEC, J.S., T.C. PFENNIGWERTH, V.J. HETHERINGTON, J.S. LOGAN, V.K. PENFIELD, J.A. FLAUTO, P.M. SHEARER, A review of lasers in healing diabetic ulcers, *The Foot*, 2004, **14**, 68–71.
15. KIM, W.S., R.G. CALDERHEAD, Is light-emitting diode phototherapy (LED-LLLT) really effective? *Laser Ther.*, 2011, **20**, 205–215.
16. KUBASOVA, T., M. FENYO, Effect of visible light on some cellular and immune parameters, *Immunol. Cell Biol.*, 1995, **73**, 239–244.
17. KUBOTA, J., T. OHSHIRO, The effects of diode laser low reactive-level laser therapy (LLLT) on flap survival in a rat model, *Laser Ther.*,1989, **1**, 127–135.
18. LANE, N., Cell biology: power games, *Nature*, 2006, **443**, 901–903.
19. LAVERY, L.A., D.G. ARMSTRONG, L.B. HARKLESS, Classification of diabetic foot wounds, *J. Foot Ankle Surg.*, 1996, **35**, 528–531.
20. LEE, G.Y., W.S. KIM, The systemic effect of 830-nm LED phototherapy on the wound healing of burn injuries: A controlled study in mouse and rat models, *J. Cosmet. Laser Ther.*, 2012, **14**, 107–110.
21. LI, P.N., H. LI, M.L. WU, S.Y. WANG, Q.Y. KONG, A cost-effective transparency-based digital imaging for efficient and accurate wound area measurement, *PLoS ONE*, 2012, **7**, 1–8.
22. MARGOLIS, D., J. TYLOR, O. HOFFSTAND, Diabetic neuropathic foot ulcers: the association of wound size, wound duration, and wound grade on healing, *Diabetes Care*, 2002, **25**, 1835–1839.
23. MARQUES, C., A. MARTINS, L.A. CONRADO, F.L. SILVEIRA, M.V. CARVALHO, The use of hyperbaric oxygen therapy and led therapy in diabetic foot, in: *Laser in Surgery: Advanced*

Characterization, Therapeutics, and System, B.J.F. Wong, D.S. Robinson, K.D. Paulsen, N. Kollias, R.S. Malek, E.A. Trowers, W.T.W. de Riese, K.W. Gregory, H. Hirschberg, S.J. Madsen, A. Katzir, L.S. Bass, K.M. McNally-Heintzelman, K.E. Bartels, L.P. Tate, eds, Proceeding of SPIE, 2004, **5312**, 47–53.

24. MEDENICA, L., M. LENS, The use of polarized polychromatic non-coherent light alone as a therapy for venous leg ulceration, *J. Wound Care*, 2003, **12**, 1, 37–40.

25. MESTER, E., A.F. MESTER, A. MESTER, The biomedical effects of laser application, *Lasers Surg. Med.*, 1985, **5**, 31–39.

26. MIN, P.K., B.L. GOO, 830 nm light–emitting diode low level light therapy (LED-LLLT) enhances wound healing, a preliminary study, *Laser Ther.*, 2013, **22**, 43–49.

27. MONSTREY, S., H. HOEKSEMA, H. SAELENS, K. DEPUYDT, M. HAMDI, K. VAN LANDUYT, A conservative approach for deep dermal burn wounds using polarized-light therapy, *Br. J. Plast. Surg.*, 2002, **55**, 420–426.

28. MONSTREY, S., H. HOEKSEMA, K. DEPUYDT, G. VAN MAELE, K. VAN LANDUYT, P. BLONDEEL, The effect of polarized light on wound healing, *Eur. J. Plastic Surg.*, 2002, **24**, 377–382.

29. MOREIRA, M.C., R. PRADO, A. CAMPOS, Application of high brightness LEDs in the human tissue and its therapeutic response, in: *Applied Biomedical Engineering*, G.D. Gargiulo, A. McEwan, eds, 2011, Intech, 2011, chapter 1, http://www.intechopen.com/books/applied-biomedical-engineering/application-of-high-brightness-leds-in-the-human-tissue-and-its-therapeutic-response.

30. PINHEIRO, A.L., D.H. POZZA, M.G. DE OLIVEIRA, Polarized light (400–2000 nm) and non-ablative laser (685 nm), A description of the wound healing process using immunohistochemical analysis, *J. Photomed. Laser Surg.*, 2005, **23**, 485–492.

31. ROBERTS, S, *LED light therapy*, heelspurs.com LLC, 2004-2012.

32. RUBINOV, A.N., Physical mechanisms of biological effect of coherent and non coherent light, *J. Phys D: Appl. Phys.*, 2003, **36**, 2317–2330.

33. SIMIC, A., P. PESCO, M. BJELOVIC, D. STOJAKOV, M. TODOROVIC, V. TODOROVIC, I. JEKIC, M. MICEV, P. SABLJAK, M. KOTARAK, Bioptron light therapy and thoracophrenolaparotomy wound healing in patients operated due to cardiac carcinoma, paper presented at the *4th International Gastric Cancer Congress*, New York, USA, April 30 – May 2, 2001.

34. SMITH, K.C., The photobiological basis of low-level laser radiation therapy, *Laser Ther.*, 1991, **3**, 19 –24.

35. SMITH, K.C., Laser (and LED) therapy is phototherapy, *Photomed. Laser Surg.*, 2005, **23**, 78–80.

36. SUTHERLAND, J.C., Biological effects of polychromatic light, *Photochem. Photobiol.*, 2002, **76**, 164–70.

37. TRELLES, M.A., I. ALLONES, E. MAYO, Combined visible light and infrared light emitting diode (LED) therapy enhances wound healing after laser ablative resufasing of photodamaged facial skin, *Med. Laser Appl.*, 2006, **21**, 165–175.

38. WATSON, M.R., K. WALLACE, R.G. GIELING, D.M. MANAS, E. JAFFRAY, R.T. HAY, D.A. MANN, F. OAKLEY, NFkappaB is a critical regulator of the survival of rodent and human hepatic myofibroblasts, *J. Hepatol.*, 2008, **48**, 589–97.

39. WHELAN, H.T., R.L. SMITS, E.V. BUCHMANN, Effect of NASA light-emitting diode (LED) irradiation on wound healing, *J. Clinical Laser Med. Surg.*, 2001, **19**, 305–314.