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PHOTOTHERAPY IN THE TREATMENT OF DIABETIC FOOT — A PRELIMINARY STUDY

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Abstract:

The first part of the publication presents a substantively insightful literature study on the essence and effects of light waves on wound healing in living organisms, including the use of phototherapy in the treatment of the diabetic foot. A knitted textile dressing was designed and manufactured for phototherapy of patients with diabetes suffering from diabetic foot syndrome (DFS). The proposed solution is intended for the treatment of dermal tissues within the patient's foot affected because of diabetic disease at an early stage. Thus, the use of a knitted dressing with incorporated fiber optic structures and powered by a semiconductor laser emitting a 405 nm light wave from its entire surface would prevent further anomalies of the patient's tissues and help to avoid surgical intervention.

Keywords:

Phototherapy, fiber optics, knitted dressing, diabetes, diabetic foot syndrome

1. Introduction

Type 2 diabetes mellitus is the most common disease in modern society and the number of people suffering from this disease is increasing dramatically every year.

Over 422 million subjects worldwide have been estimated to suffer from diabetes, including approximately 25–30% of people whose disease has not yet been diagnosed. In Europe, up to 59.8 million people may be affected by diabetes. About 1.6 million people die from diabetes all over the world every year. According to the data of the Central Statistical Office in Poland, nearly 3 million people, which is approximately 8.8% of the adult population, suffer from diabetes, and 20% of them are unaware of it. Among subjects >70 years of age, as many as 20% have diabetes. Type 2 diabetes accounts for >80–90% of all cases of diabetes [1–2].

If diabetes is left untreated or improperly treated, it carries a risk of several complications such as diabetic retinopathy, diabetic nephropathy, ketoacidosis, lactic acidosis, cardiovascular disorders, renal complications, and the most common complication referred to as diabetic foot syndrome (DFS) [1–2].

DFS is a condition involving damage to the nerves and blood vessels within the lower extremity due to chronic hyperglycemia. The healthy human body regulates the condition of the skin by stimulating the glands to produce adequate amounts of sebum and sweat. In the body of a diabetic patient, the process of sebum secretion is disturbed, the skin becomes dry, and susceptible to damage over time. Damage to the nerves and ischemia result in losing the sensation of pain in the affected limb, so the patient does not feel the discomfort caused by cuts or abrasions, which can lead to infection of tissues at a later stage. Infection of the foot in a diabetic patient can take various forms ranging from a mild inflammation of the subcutaneous tissue to severe gangrene. In the latter case, the infection, usually of a multibacterial nature, spreads rapidly and improper management of the wound healing process leads to the formation of deep ulcers, as well as weakening of bones and joints. Approximately 15–25% of diabetics develop foot ulcers and DFS and the risk of limb amputation in diabetic patients is several times higher than in subjects without the condition [1–6]. Sample photographs of diabetic foot are presented in Figure 1.

Diabetics who are aware of their condition most often follow a diet with a low glycemic index, use appropriate medications that regulate blood glucose levels, take care of hygiene and oiling of the skin, and wear appropriate shoes. However, this is not always sufficient, in some cases, it is necessary to use appropriate dressings, antibiotic therapy, and sometimes also to remove necrotic tissue. It is estimated that up to 15% of patients may undergo a limb amputation at some stage in their lives [1–6]. Since conventional treatment of chronic wounds often fails, additional methods such as vacuum dressings, hyperbaric oxygen therapy, topical use of carbon dioxide, and other methods are used in daily practice [1–8].


Figure 1. Feet of diabetic patients with DFS complications [7]. DFS, diabetic foot syndrome.

2. State-of-the-art research concerning the effect of light waves in wound healing

2.1 In vivo laboratory studies on the application of light in the treatment of slow-healing wounds in living organisms

There is ample evidence that treatment with polychromatic or monochromatic light (phototherapy), in particular infrared light and/or radiation with an energy of $<$10 J/cm^2 and a wavelength of 600–850 nm, promotes the repair of the skin, ligaments, tendons, bones, and cartilages in the wounds of experimental animals and ulcers of various etiology [8].

Studies by de Sousa *et al.* [9] using rodents evaluated the effect of irradiation with different wavelengths on the number of fibroblasts during wound healing. The red light emitted by light-emitting diode (LED; 700 $\pm$ 20 nm, 15 mW, 10 J = cm^2) and green light emitted by LED (530 $\pm$ 20 nm, 8 mW, 10 J = cm^2) were found to be associated with an increase in the number of fibroblasts in rodents exposed compared with the control group. The use of green and red LED lights effectively increases the proliferation of fibroblasts in rodents [9, 10]. In a study of laboratory rats, Dungel *et al.* [11] showed that irradiation for 10 min, for 5 consecutive days, with both blue (470 nm) and red (629 nm) LED lights can improve wound healing by improving angiogenesis. LED therapy at both wavelengths significantly increased angiogenesis in the subepidermal and muscle layers, resulting in better tissue perfusion. Tissue necrosis has been significantly reduced, and contraction much less pronounced in groups treated with LED light of both wavelengths. Treatment of tissues with LED irradiation using both wavelengths improved early wound healing [11, 12]. A study carried out in laboratory mice showed that a single exposure to low levels of red or near-infrared light significantly stimulated wound healing in the animals. Shrinking of the edges of exposed wounds within the first 24 h was observed as opposed to swelling of the wounds in the control group. The 820 nm wavelength demonstrated the best positive healing properties compared with 635 nm, 670 nm, and 720 nm [13, 14].

In a study using rats with induced diabetes, 890 nm and 660 nm LED irradiation (a complex system, 32,890 nm LEDs and 4,660 nm LEDs, 100 mW/cm^2) were used. The wounds were irradiated for 30 s, which resulted in the dose of 3 J/cm^2. The combination of 660 nm and 890 nm light used in the study promoted tissue granulation and rapid healing of diabetic ulcers that had not responded to other forms of treatment [15, 16]. In diabetic rats, a light dose of 5 J/cm^2 and 10 J/cm^2 was able to alleviate the impaired healing of diabetic wounds. A group of 25 LED photons emitting 510–543 nm, 594–599 nm, 626–639 nm, 640–670 nm, and 842–872 nm wavelengths with an output power of 272 mW was used. The study shows that polychromatic LED therapy affects full-thickness wound healing in rats without diabetes and with diabetes. The effect of polychromatic LED therapy in full-thickness wound healing in a diabetic model using 5 J/cm^2 and 10 J/cm^2 doses has been promising [17, 18]. In Al-Watban's rat study, different LED-emitted wavelengths (532 nm, 633 nm, 810 nm, 980 nm, 10,600 nm, and 510–872 nm) and light intensities (5 J/cm^2, 10 J/cm^2, 20 J/cm^2, and 30 J/cm^2) were used. Phototherapy with a wavelength of 633 nm accelerated healing and showed the best therapeutic effects on diabetic wounds and burns. For the treatment of DFS, irradiations with 633 nm light wavelength should be performed three times a week at an intensity of 2.35 J/cm^2 [19, 20]. Santos *et al.* [21] irradiated wounds in mice with diabetes with wavelengths of 680 nm or 790 nm (2.5 J/cm^2) and demonstrated an improvement in angiogenesis compared with the control group with an indication of better effects obtained with 790 nm [22].

2.2 Clinical studies on the use of phototherapy in the treatment of wounds in patients with diabetic foot

Phototherapy has also been proven to accelerate tissue repair by promoting fibroblast proliferation, synthesis of collagen, and other tissue components, and by strengthening the cellular and subcellular processes which are needed to intensify the formation of Type I and III procollagen mRNA stores, ATP synthesis, and lymphocytic activity. In diabetic patients, chronic hyperglycemia leads to uncompensated levels of metalloproteases, which degrade excessively the extracellular matrix, reduce the tensile strength of the skin, and delay wound healing. Phototherapy has also been demonstrated to stimulate collagen synthesis in diabetes. It is possible that phototherapy may promote the treatment of DFS by stabilizing the extracellular structural support required to facilitate wound healing in diabetic patients. The use of phototherapy may result in the stimulation of cytokines and growth factors in the wound healing process. Phototherapy stimulates the expression of proliferation, migration, survival, and healing regulators, such as primary fibroblast growth factor, interleukin and platelet growth factor, beta-transforming growth factor, and the phagocytic activity of macrophages. The recruitment of these key cytokines and growth factors is an important factor contributing to the treatment of DFS. The proliferation and differentiation of different cell lines play an important role in accelerating the treatment of DFS [23, 24].

On the overall, *in vitro* and *in vivo* studies and human clinical trials have confirmed the role of phototherapy in improvement in the healing of diabetic wounds. All the published clinical studies have shown positive results of the use of phototherapy in the treatment of DFS. In view of the lack of other effective treatment options for DFS in the published medical literature, phototherapy may become an alternative, complementary therapeutic option or a basic treatment of patients with DFS [25].

The main rationale for undertaking the studies in this area has been the complete absence of a form/action for secondary prevention that can be used in patients with Type 1 and Type 2 diabetes. The patients remain under outpatient care, involving primarily and only the control of glycemia. In addition, patients properly educated during the therapeutic process choose the appropriate footwear and socks to reduce the risk of recurrences and carry out self-monitoring of the skin condition of their feet. Despite all these elements, the risk of recurrence of active DFS (recurrence of ulcers) is very high. In as many as 15% of patients, the ultimate loss of the affected limb occurs. It should be emphasized that amputation of the extremity above the knee is associated with an 80% risk of death within 5 years after the amputation. This mortality rate is higher than that associated with the most malignant cancers (e.g., pancreatic cancer or lung cancer).

Scientific research is carried out in the leading centers in the world, especially in highly developed countries, where, based on literature reports, one can see the rationale for the effectiveness of phototherapy for hard-to-heal, extensive wounds, for different technological solutions applicable to different cases and stages of the disease.

2.3. Lasers and LEDs for wound treatment

In recent years, numerous studies have demonstrated the beneficial effects of low-level laser therapy (LLLT) in the treatment of various pathologies [26–38].

LLLT, also called soft laser, is known for delivering direct biostimulating light energy to the body cells. The absorbed laser energy stimulates the molecules and atoms of the cells, but does not cause a rapid or significant increase in the temperature of the tissues. While most LLLT devices illuminate the treatment area from a distance, the term LLLT also describes a new method of laser acupuncture, called a laser needle [39]. The biological action of the light wave is omnidirectional. In addition to improving peripheral nerve regeneration, reducing inflammatory reactions and improving bone formation, the role of light therapy in supporting wound healing and angiogenesis has been demonstrated [25]. Many studies have proven the effectiveness of LED phototherapy in the treatment of DFS ulcers. This method of light wave emission is safer than low-level laser emission LLLT due to the lower risk of cell damage and no temperature increase, since the LED phototherapy effect is chemical rather than thermal. The energy supplied to the cells causes slight and minimal temperature changes, usually in the range of 0.1–0.5 °C. [26, 27]. This type of phototherapy provides a more superficial, even energy distribution with lower power density and longer duration of treatment than LLLT. In some clinical studies, phototherapy was performed each time for approximately 4–50 min, twice a week or twice a day, for a total of 15–90 days [23]. The effectiveness of this therapy in the case of DFS ulcers is very high. In the study by Rohringer *et al.* [9], three types and lengths of light waves were compared. The LED lamps for phototherapy were supplied by Repuls Lichtmedizintechnik GmbH, Austria. LED light of wavelengths 475 nm (blue), 516 nm (green), 635 nm (red), or no light (control group) was used. All LED devices had a peak irradiation intensity of 80 mW/cm^2, which was measured with a USB 2000 spectrometer (Ocean Optics, FL, USA). Taking into account the pulse rate of 50% and the repeat frequency = 2.5 Hz, the average irradiation intensity reached 40 mW/cm^2. The administered daily dose amounted to 24 J/cm^2. Irradiation was carried out at room temperature for 10 min from a distance of 2 cm. In the untreated control group, the wound area decreased by only 28.7% ± 11.1% within 6 h, in the blue light group there was a decrease of 32.0% ± 9.6%, in the red light group 36.6% ± 6.3%, and in the green light group 40.1% ± 8.0%; the above differences were statistically significant [25–27]. Clinical studies correlate the cellular effects and biological processes and determine the usefulness of LLLT in wound healing. In a double-blind, placebo-controlled study, the therapeutic effect of combined 660 nm and 890 nm laser treatment on 23 diabetic ulcers of the lower leg was tested during 60 days, 75 days, and 90 days of treatment by Minatela *et al*. The ulcers treated with placebo were cleaned, covered with 1% silver sulfadiazine cream, and treated with placebo laser irradiation <1.0 J/cm^2. Within the first 30 days, their severity even worsened. Ulcers in the treatment group received the same treatment but the administered dose was 3 J/cm^2. On day 30, ulcers in the treatment group achieved 56% higher granulation and 79.2% faster healing than in the placebo group, and similarly higher granulation and healing rates continued all the time. In the treatment group, 58.3% of ulcers were healed completely and 75% achieved 90–100% healing by day 90. In the placebo group, however, only one ulcer was completely healed and none of the ulcers healed >90% [39, 40]. In a clinical study, Zhou *et al.* [39] investigated the healing of irradiated (633 nm) chronic foot ulcers in 60 patients. In 28 patients, conventional therapy was used and 32 received conventional therapy plus LLLP. There were 14 patients with diabetes in the conventional treatment group and 18 patients with diabetes in the conventional treatment plus LLLP group. (Other causes of ulcers are not described in detail.) The ulcers were evaluated by reducing the size and immunohistochemical analysis of 70 heat shock protein (HSP70) positive cells. The expression of the protein and mRNA of heat shock factor 1 (HSF1) and HSP70 was determined by a reverse transcription polymerase chain reaction (RT-PCR). Compared with the conventional therapy group and normal skin sections, as a control group, HSF1 and HSP70 expression in the laser group was significantly higher, as it was observed in the grayscale in the Western blot bands, as well as the levels of HSF1 and HSP70 RNA in RT-PCR. Due to the laser-activated mechanism of endogenous heat shock protection in cells on the wound surface, LLLT plays a role in facilitating the healing process of chronic skin ulcers [39, 41]. Landau *et al*. [40] investigated the effects of visible light broadband (400–800 nm) in a double-blind, placebo-controlled, randomized study of 16 patients suffering from diabetic or non-diabetic foot ulcers. The treatment group (n = 10) received light irradiation of the wound twice a day at 43.2 J/cm^2, while the placebo group (n = 6) received wound light irradiation with the same device at only 2.4 J/cm^2, which was considered a non-therapeutic dose. All patients received conventional wound treatment. At the end of the follow-up period, all wounds in nine patients in the treatment group were closed (90%), whereas in the placebo group only two out of six patients (33%) had closed wounds, which were assessed according to Wagner classification for foot ulceration and based on width/length measurements. Laser therapy reduces the inflammatory response and provokes the greater proliferation of myofibroblasts in experimental skin wounds. No adverse effects of the therapy were observed [39, 42].

Clinical studies conducted in many centers confirmed the role of phototherapy in the improvement of healing of wounds of different etiology. All the published studies have demonstrated positive results of phototherapy in the treatment of patients with diabetes mellitus [23–41].

As there is a lack of effective treatment options for DFS in published medical literature, phototherapy may become an alternative, complementary therapeutic option, or a basic treatment of DFS. There are numerous scientific reasons for the use of light in the group of patients after the healing of active ulcers and in patients with diabetes mellitus and with the signs of the so-called “high risk” foot, i.e., the foot, which has characteristics that significantly increase the risk of developing DFS [1–41].

3. Medicinal applications of optical fibers

Fiber optics has long been used in medicine, among others, in endoscopy and laparoscopy, providing the possibility of more accurate imaging diagnostics. In addition, optical fibers are used to build flexible endoscopes equipped with a light source and an optical system called fiberscopes. Thanks to fiber optics, diagnostic tests are increasingly possible, avoiding the need for extensive tissue incisions or X-rays, which not only failed to give such clear images but were also not indifferent to the patient’s health [43, 44].

A classic fiber optic cable is a closed structure made of glass or plastic that uses light to transmit information. In other words, a fiber optic cable is an optical fiber—a dielectric transmission medium, acting simultaneously as an electrical insulator and an optical conductor, based on fibrous technology, and its task is to transmit optical signals without loss or distortion. Fiber optics are made up of a centrally located core, a surrounding outer layer, and a protective coating (a jacket). These structures can take the form of a single fiber, a bundle of fibers, or solidified fibers (a fiber optic plate, [FOP]). Fiber optics is widely used in optotelecommunication, biomedicine, sensor technology, metrology, military systems, and classic lighting systems. The optical fibers are used as sensors to measure different values such as temperature, pressure, location, stress, and deformation, which is also well-known [43].

The fiber optic dressing mentioned in the utility model application CN208958511U [45] consists of two layers, one of which is a layer of optical fibers placed on the wound and the other is a removable layer of gauze attached with a buckle to the fiber layer. In the optical fiber layer, the fibers are arranged transversely and longitudinally, and are cross-connected into the form of a fabric mesh, so that between the fiber optics there are visible spaces in the shape of parallelograms. Light-emitting plates of cylindrical shape fixed permanently to the fiber mesh at the intersections of transverse and longitudinal fibers, projecting out of the plane of the fiber mesh, are the light sources. The dressing also contains a light-collecting plate. This dressing is cumbersome to use due to the use of a buckle connecting its layers, as well as the use of light sources protruding from the dressing surface. There is no information in the document on the type of light used, as well as on the presence of sensors in the dressing to monitor the condition of the tissue, which means that the use of this dressing for a specific purpose must be preceded by a series of tests and experiments.

The description of the patent application WO2020/064937 A1 [46] reveals a two-layer fiber optic dressing, the fiber layer of which placed on the wound is one or more optical fiber systems in the form of a mesh or a zig-zag, superimposed on top of each other, and the top layer is a replaceable layer of gauze, spacer knit, etc. Optical fibers emit a light wave only at the ends of the fibers or from holes drilled in them. Although the document indicates the light wavelength range used was 300–2,000 nm, there is no information about how the light wave was used for treatment and how it had been achieved or how to achieve, suggesting that the fiber optics act only as sensors to detect the properties of the wound. The dressing may have in its structure, in addition to the fiber optic mesh, additional diagnostic factors, in the form of pH or thermochromic strips reacting to heat emitted from the wound and suggesting inflammation signaled by higher temperature, but these are ad hoc and disposable solutions.

4. Knitted optical fiber dressing using fiber optic and laser technology—conceptual testing

To meet the expectations of patients with DFS and to improve the quality of life of diabetic patients, a dressing device was developed by the authors of this publication. Such a dressing will meet several requirements, the most important of them are high therapeutic efficacy, simple application, and user safety. Therefore, it was decided to combine a knitted product with optical fibers emitting a specific light wavelength along its entire surface, which will be powered by a semiconductor laser. Scientists have already proposed ways to combine fiber optics with knits, although these products were not designed for medicinal use [47–51, 43, 52].

A rarely used type of optical fiber, a lateral propagation optical fiber, was used for research purposes. It is a so-called light diffuser fiber and is most often produced by mechanical incision of the fiber so that a beam dispersion can be obtained. The appearance of a lateral propagation optical fiber is shown in Figure 2.

The solution of a textile diagnostic and therapeutic dressing for wounds of patients with DFS uses light of a specific wavelength to accelerate the treatment and diagnosis of foot wounds. The textile dressing, intended for management of DFS wounds, has optical fibers coupled in a disconnectable manner with a light source, including diagnostic elements, is a single-layer device and constitutes a knitted layer made of natural mineral fibers, synthetic fibers, man-made fibers, and others, containing transparent gradient optical fibers emitting light from the lateral surface, placed in the entire structure or a part of its structure, in the form of mesh eyes or weft, introduced in the process of knitting. As a light source, the dressing contains a semiconductor laser or an electroluminescent diode, emitting a light wave of a specific length. The dressing may contain flat-shaped temperature and humidity sensors designed to monitor the condition of the foot skin, attached to the knitted layer on the wound side, coupled with a device for recording and displaying the temperature data. A semiconductor laser or an electroluminescent electrode emitting light waves within the 400–1,200 nm range is used. The 400–500 nm wavelength light is designed to activate anti-inflammatory processes and to exert antiseptic and bactericidal effects on the wound; the 570–590 nm wavelength is intended to relieve the skin irritation, improve the lymph flow, boost the body's protective system, and stimulate collagen production; the 630–700 nm wavelength is used to improve the blood supply, stimulate the metabolism of skin cells, and accelerate wound healing; the 520–540 nm wavelength is used to control discoloration and reduce swelling; and the 800–1,200 nm wavelength is used to accelerate wound healing and support the treatment of ulcerations. The dressing is a layer of flat knitted fabric. The time of the phototherapy procedure and the type of light emitted on the diseased foot is selected by the attending physician based on the anamnesis and medical history. The dressing can emit a light wave on the entire contact surface, or a fragment of it, which is achieved by personalizing the dressing, as directed by the attending physician. The patient can use it himself at home. It performs both the function of accelerating wound healing and the functions of monitoring the condition of the wound. The schematic diagram of the dressing is shown in Figure 3.

It was decided to supply the incorporated fiber optics with a 405 nm light wave since it has bactericidal and regenerative properties, penetrates only through the epidermis and stops in the structure of the dermis (radiation penetration depth not exceeding 1 mm), which limits the development of microbes and promotes the healing process of diabetic foot wounds.

In future research, the authors intend to power the fiber optics with other light parameters. Differences in the penetration of light radiation of different wavelengths through the tissues are presented in Figure 4.

The intensity of radiation, which will be administered to the patient as well as the area exposed to irradiation, is also very important in the case of phototherapy of diabetic foot. The dressing may emit light over the entire contact surface of the device, or over a part of it (e.g., a light wave may be emitted by a 5 cm^2 area), which will be achieved by personalization of the dressing, or developing an appropriate shape of the light-emitting element selected for the patient, as recommended by the attending physician.

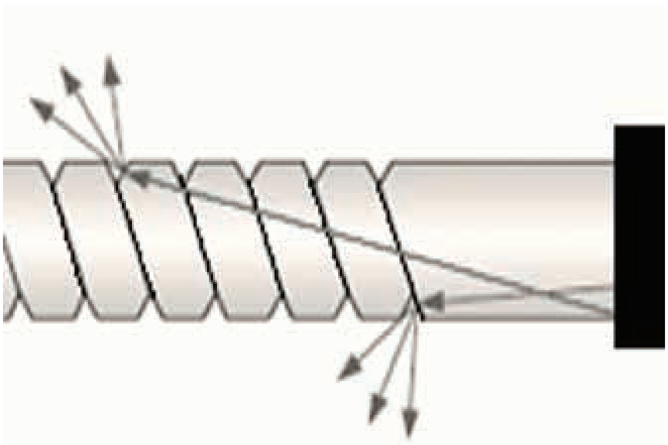

Figure 2. A lateral propagation optical fiber.

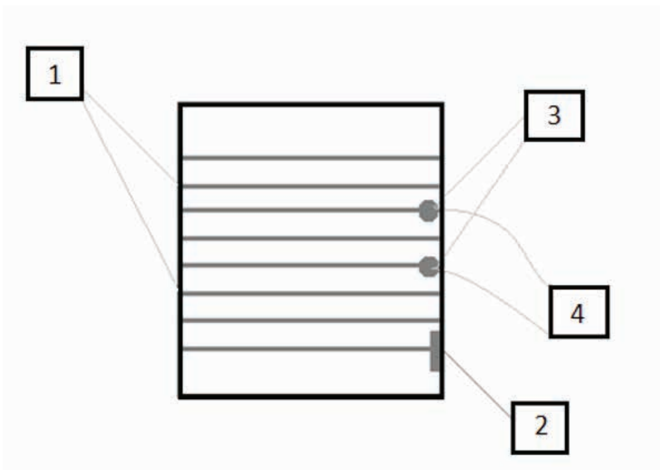

Figure 3. 1-optical fibers or LEDs, 2-light source, 3-sensors, 4-recording device. LED, light-emitting diode.

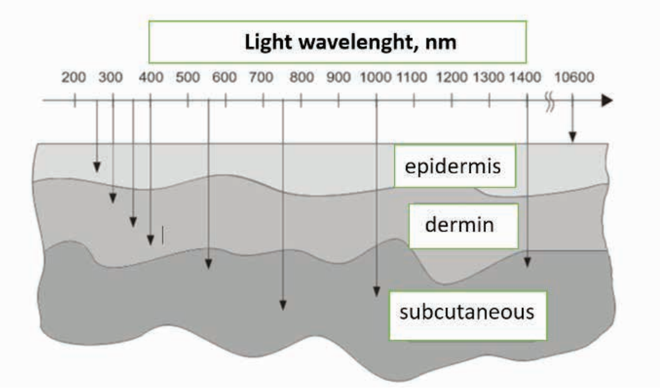

Figure 4. Differences in the depth of energy penetration through the skin depending on the radiation wavelength [51].

5. Knitted optical fiber dressing technology

A dressing product measuring 100 mm x 300 mm, in the form of a row knitted fabric with a double-right weave, was made on a double-bearing flat crochet machine with needle number 3.5. Polyester yarn of 210 tex linear weight and lateral propagation optical fibers with an external diameter of 0.75 mm made of poly(methyl methacrylate), PMMA, were used to manufacture the dressing, As a result, a textile dressing of 473 g/m^2 surface mass and 0.43 mm thickness was obtained. The wale density of the knitted fabric was 51 with the course density 45. Figure 5 shows the scheme of the manufactured product and the positive effects of light emission in the context of composite—knitted dressing with fiber optics emitting laser light of a specific wavelength.

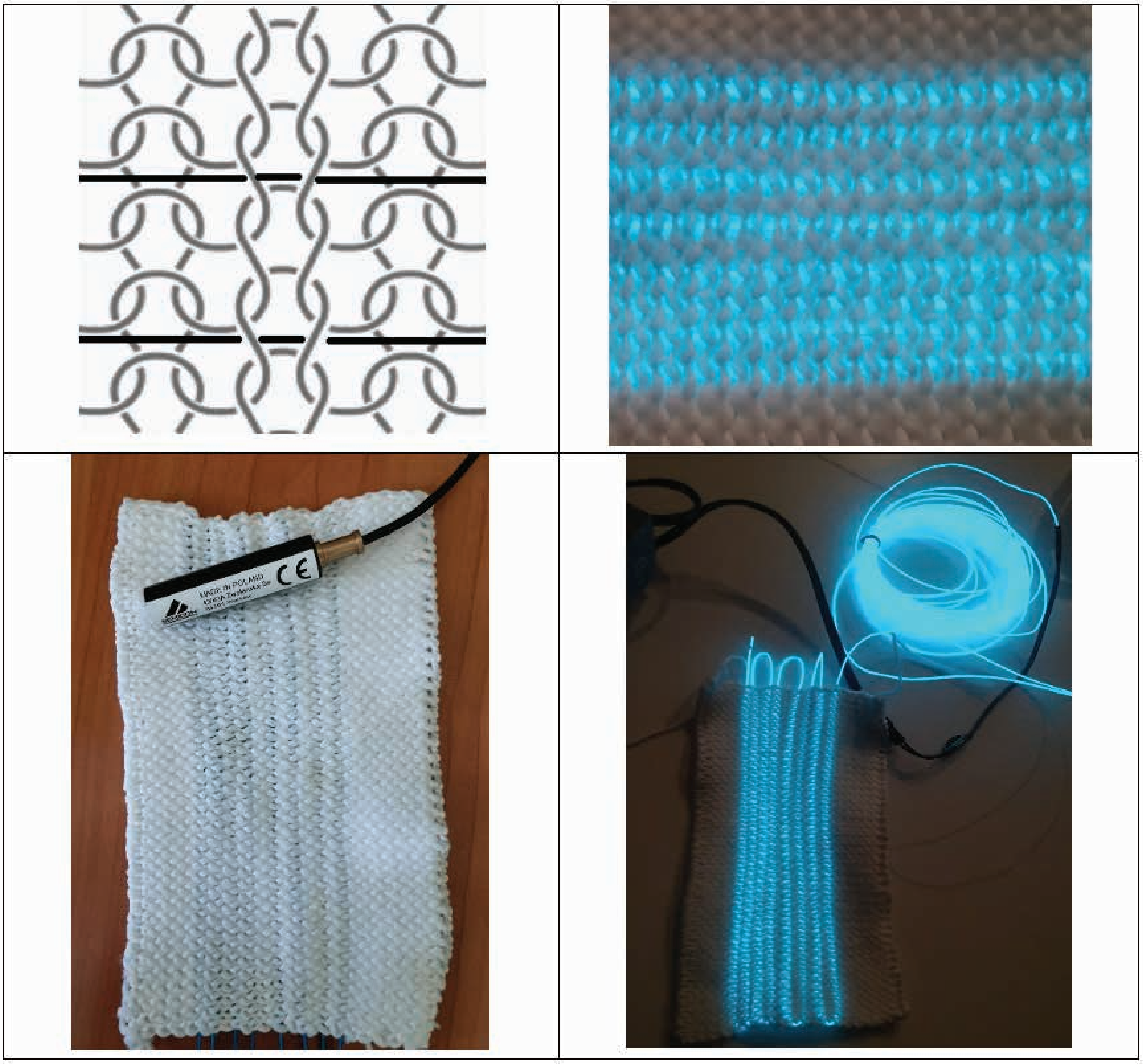

Figure 5. Structure of knitted fabric with fiber optics and photograph of the photo-dressing produced.

Table 1. Technical parameters of the Semicon laser.

Safety class	3R acc. to PN-EN 60825-1:2014
Wavelength	Λ = 405 nm ± 10 nm
Optical power	5 mW ± 0.5 mW
Power supply	AC adapter 230V AC/3.5VDC/150 mA with LEMO connector
Power consumption	<100 mA
Laser output beam diameter	4.5 mm ± 05 mm
Beam divergence	<1.5 mrad
Factory set Focus distance	Infinity

The optical fibers were powered by a 405 nm light wave using a Semicon ML-27P-405-5 universal industrial module. The laser parameters are presented in Table 1.

The research on the development of knitted fabric structures with incorporated light-emitting elements is still ongoing and the result is a patent application number P.434454.

6. Summary

1. Diabetes is the most common health problem in modern society and the number of people suffering from this condition is increasing dramatically every year. It is estimated that >422 million people worldwide are affected and this is an extremely important medical, social, and economic problem. If left untreated, or poorly treated, diabetes carries a risk of several complications, including DFS. Infection of the foot can take various forms ranging from a mild inflammation of the subcutaneous tissue to severe gangrene. Since pharmacological or surgical treatment of chronic wounds often does not produce the desired results, additional methods such as vacuum dressings, hyperbaric oxygen therapy, topical use of carbon dioxide, and others, including phototherapy, are used in practice.

2. *In vivo* laboratory studies on the use of light in the management of hard-to-treat wounds in living organisms demonstrate that treatment with polychromatic or monochromatic light (phototherapy), in particular, infrared light and/or infrared radiation of 600–850 nm wavelength, promotes rapid healing of diabetic ulcers that have not responded to other forms of treatment. In rodents with diabetes, a light dose of 5 J/cm^2 and 10 J/cm^2 was able to alleviate the impaired healing of diabetic wounds.

3. Clinical studies on the use of phototherapy in the treatment of wounds in patients with DFS show that phototherapy accelerates tissue repair by promoting the proliferation of fibroblasts, the synthesis of collagen and other tissue components, and by boosting the cellular and subcellular processes that are needed to intensify the formation of Type I and III procollagen mRNA stores, ATP synthesis, and lymphocytic activity. Phototherapy can promote the treatment of DFS by stabilizing extracellular structural support and by stimulating cytokines and growth factors to support wound healing. All the published clinical studies have demonstrated positive results of phototherapy in the treatment of DFS.

4. In recent years, numerous clinical studies have indicated the beneficial effects of LLLT and the use of LED in the treatment of various pathologies, including the treatment of DSF ulcers. As there is a lack of effective treatment options for DSF in the published medical literature, phototherapy may become an alternative, complementary therapeutic option or the basic method of treatment. There are a lot of scientific reasons for the use of light in the group of patients after healing of active ulcers as well as in patients with diabetes mellitus and with the signs of the so-called “high risk” foot.

5. Knitted optical fiber dressing was achieved with the advantage of the fiber optic technology, and further a laser was developed by the authors of this publication—research workers from the Technical University of Lodz and the Medical University of Lodz for this application. It was decided to combine a knitted product with optical fibers emitting a specific wavelength of light on its entire surface, which are powered by a semiconductor laser. The textile dressing contains also diagnostic elements in the form of temperature and humidity sensors. Within the framework of the study, a prototype dressing of 100 mm □ 300 mm was produced in the form of a double-right row-knitted fabric made of polyester threads and lateral propagation optical fibers of 0.75 mm external diameter, made of poly(methyl methacrylate). The optical fibers were powered by a 405 nm light wavelength. Research into the development of knitted structures with incorporated light-emitting elements is still ongoing, and the result of this work is a patent application number P.434454.

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