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Pilot Study on Therapeutic System Design for Pressure Ulcer Management: Feasibility and Initial Findings

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Abstract
Pressure ulcers or Decubitus Ulcers are injuries to the skin and underlying tissue due to prolonged pressure and friction that cause heat that damages skin tissue, generally occurring in bedridden patients who have difficulty moving and changing their position. Pressure ulcer treatment relies on conventional methods, with prevention as the primary step. Wound care is often overcome by cleaning the wound and changing the bandage regularly, although this method requires a long time and patience until the wound can gradually improve. Prevention is done by helping to change the patient's sleeping position regularly every few hours. This study aims to create a device that can help accelerate the healing process of pressure ulcers by using light therapy exposed to skin with pressure ulcers. A few variations of experiments were carried out on several mice that were conditioned to have pressure ulcers. Hence, the wound's healing time rate in each mouse with no treatment, treatment with 50% light intensity, and 100% light intensity, respectively, are 7%, 34%, and 82%. This pilot study showed improvement in pressure ulcers on the surface of the mouse skin within seven days, where wound healing was 2 to 3 days faster than without treatment. In conclusion, this study has demonstrated the feasibility of providing a therapeutic healing effect on the skin of mice and can be further developed in the future.
Keywords: *therapy device, pressure ulcer, ultraviolet light, therapeutic system, decubitus ulcer*

Abstrak
Luka tekan atau Ulkus Dekubitus adalah cedera pada kulit dan jaringan di bawahnya akibat tekanan dan gesekan yang berkepanjangan sehingga menimbulkan panas yang merusak jaringan kulit, umumnya terjadi pada pasien tirah baring yang sulit bergerak dan mengubah posisinya. Saat ini, perawatan luka tekan masih mengandalkan metode konvensional dengan pencegahan sebagai langkah utama. Perawatan luka lebih sering diatasi dengan membersihkan luka dan mengganti perban secara rutin walaupun cara ini membutuhkan waktu dan kesabaran yang cukup lama sampai luka dapat berangsur membaik. Sedangkan pencegahan dilakukan dengan membantu merubah posisi tidur pasien secara rutin setiap beberapa jam. Penelitian ini bertujuan untuk menciptakan suatu divais yang dapat membantu mempercepat proses penyembuhan luka tekan dengan menggunakan terapi cahaya yang dipaparkan pada kulit yang mengalami luka tekan. Sejumlah variasi percobaan dilakukan pada beberapa tikus yang dikondisikan mengalami luka tekan. Laju waktu penyembuhan luka pada masing-masing tikus tanpa perlakuan, perlakuan dengan intensitas cahaya 50%, dan perlakuan dengan intensitas cahaya 100% berturut-turut adalah 7%, 34%, dan 82%. Dengan demikian, hasil dari penelitian pilot ini menunjukkan perbaikan luka tekan pada permukaan kulit tikus dalam waktu 7 hari, dimana penyembuhan luka lebih cepat 2-3 hari dibandingkan dengan tanpa pengobatan. Kesimpulannya, studi ini telah dapat menunjukkan kelayakan dalam memberikan efek terapi penyembuhan pada kulit tikus dan dapat dikembangkan lebih lanjut lagi ke depannya.
Kata Kunci: *alat terapi, luka tekan, sinar ultraviolet, sistem terapeutik, ulkus dekubitus*

1. Introduction

Bed rest is a treatment that limits patients' staying in bed as part of their therapy. When patients lie down or sit, their body weight puts pressure on bony prominences, increasing the risk of skin damage if this pressure lasts for a long time [1]. Pressure ulcers, or Decubitus Ulcers, are skin and underlying tissue injuries caused by prolonged pressure and friction. This condition generally occurs in patients who cannot change body position and are bedridden for a long time [2], [3]. Bedsores reduce the quality of life of patients because they

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complain of physical and mental pain during the illness and are burdened with the medical costs of treating and managing pressure ulcers.

The current method for preventing decubitus ulcers begins with risk evaluation, skin condition assessment, activity management, optimal nutritional intake, and ensuring the patient's bed surface can reduce friction and pressure. It is not quickly hot due to skin friction with the bed surface[2]–[4]. This comprehensive approach, called bundle care, has been proven effective and recognized in developed countries. However, in Indonesia, the application of bundle care is still limited, with only specific methods implemented separately and less coordinated [5], [6]. Treatment of pressure ulcers requires periodic position changes to prevent prolonged pressure on the skin and repeated washing and dressing of the affected area. In addition, we are performing surgery to remove dead tissue, using negative pressure therapy, and giving medications such as ibuprofen and antibiotics. This treatment method is expensive because it requires periodic handling by health workers and caregivers [7], [8]. Others included retrospective observational studies ￼, machine learning or artificial intelligence [9], and surgery [10].

Treatment using technology that has so far been reported in several studies to provide quite significant results is phototherapy [6], for example, for diabetic patients [11][12][13], which involves adjusting the intensity of the light to the condition of the decubitus ulcer lesion during therapy, such as low-intensity laser therapy and ultraviolet light therapy. Laser therapy activates blood circulation and encourages inflammatory cell migration and wound regeneration [5][14]. At the same time, the therapeutic effect of ultraviolet light prevents the development of lesions in early-stage pressure ulcers by increasing blood supply to the skin, encouraging cell growth, and sterilizing the skin [6]. While treating pressure ulcers using infrared treatment has side effects such as dry treatment areas, its efficacy is limited to a smaller area than conversion heat treatment. Likewise, negative pressure therapy and the effects of the shockwave generation method have low efficacy [7][15].

To overcome the weaknesses of the three types of treatments, a study developed a device using a biophotonic sensor of red light with a wavelength of 660 nm. Still, the application is skin contact [6]. This wavelength is included in the type that can be well absorbed into the skin, promoting metabolic cell activity and activating cell regeneration to treat skin diseases. This wavelength is reportedly more effective than 365, 455, and 545 nm. Those studies are ongoing to achieve optimal results and can be quickly and safely used on humans. Therefore, this study was conducted to design another alternative phototherapy device that is more affordable and can help accelerate the healing process of pressure ulcers by utilizing light irradiation with a specific wavelength on the surface of the skin suffering from pressure ulcers within a certain period. We named this device "*Perangkat Akselerasi Penyembuhan Ulkus*" (PAPU) or the pressure ulcer therapeutic accelerator.

2. Research Methodology

This session has three parts: system design, experiments, and image processing techniques. The system design session describes the details of the system design. The experiment and materials session describes how experiments are conducted to prove the system's effectiveness or performance. The image processing techniques session describes the image processing techniques used in this study.

2.1. System design

The various hardware components used in the PAPU system (see **Fig. 1**) include all the elements required for implementation, such as the microcontroller, high-power LED and the driver, relay, AC-to-DC converter, and display. An Arduino Uno microcontroller board based on the ATMega328 chip features 14 input/output pins, with 6 of them capable of PWM output and six serving as analog inputs. A high-power LED (HPL) is a type of LED that produces a more substantial light intensity than other LEDs. However, this type tends to heat up faster than other LEDs. In this study, PAPU uses six deep red HPLs with a light wavelength of 660 nm. To regulate and ensure the HPLs operate efficiently and safely the power supply to the LED, PAPU uses an LED driver. This device ensures the LED receives the correct voltage and current, as LEDs are susceptible to fluctuations in electrical current.

In this circuit, the LED driver provides voltage to the LEDs arranged in parallel to supply the appropriate current and power according to the LED's requirements. The LED driver used in this device has a power rating of 3W, a current of 300mA, and a voltage range of 3-12V. A relay, an electronic switch controlled by an electrical current, sets the lights on according to the user's choice. The relay operates when voltage is applied to pin one and ground to pin 2, causing the CO (Change Over) pin to switch from the NC (Normally Closed) pin to the NO (Normally Open) pin. This system uses an AC-to-DC voltage converter as a power adapter for the HPLs. A 16x2 CMOS LCD (Liquid Crystal Display) is installed on the user interface console to display the user's option mode.

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Fig. 1: Components used in the PAPU system

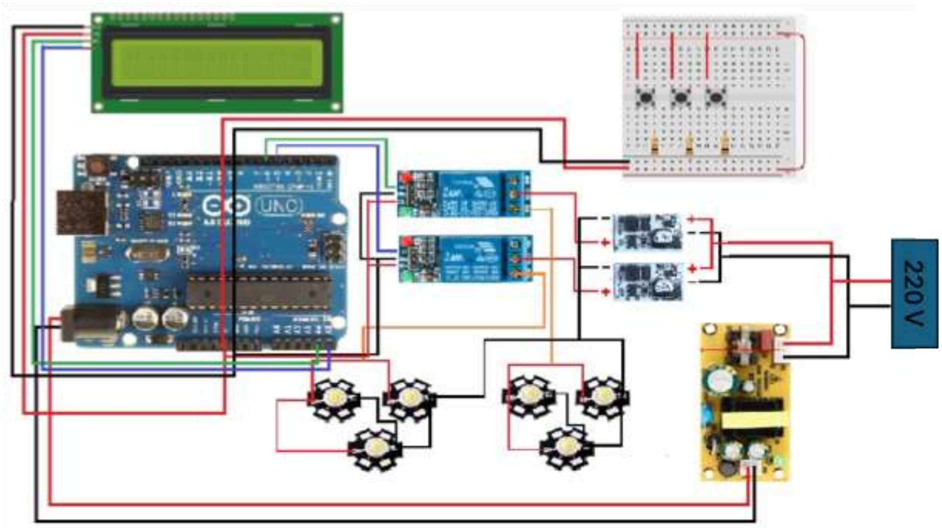


Fig. 2: Electrical schematic of the system

The therapeutic device for pressure ulcers uses various electronic components to regulate and monitor light therapy. The microcontroller manages the process and is connected to a relay that controls the power flow to the HPL, which provides light for the treatment. A push button is used to help users select the time and light intensity settings. The settings and device status are displayed on an LCD connected to the Arduino, giving users visual feedback. A resistor regulates the current and protects the electronic components from damage. Additionally, an AC-DC converter transforms AC power from the source into the DC power the electronic components need. **Fig. 2** describes the electrical schematic of the PAPU system. **Tables 1 to 3** represent the pin configurations of each connected component.

Table 1. Arduino Pin Configuration with Push Button, Relay, and LCD

Arduino Uno	**Push Button**
PIN GND	Resistor & PIN 4
PIN 5V	PIN 1
PIN 2	PIN 4
PIN 3	PIN 4
PIN 4	PIN 4
	Relay
PIN 5	PIN IN
PIN 6	PIN IN
PIN 5V	PIN VCC
PIN GND	PIN GND
	LCD I2C
PIN A5	PIN SCL
PIN A4	PIN SDA

PIN 5V	PIN VCC
PIN GND	PIN GND

Table 2. Configure Relay Pins, HPL, and HPL Driver

Relay	LED	HPL Driver
PIN NO	PIN +	NC
PIN COM	NC	Cable +

Table 3. Pin Configuration of AC to DC 9V Converter and Led Driver

220 V AC	AC-to-DC Voltage Converter	HPL Driver
GND	GND	GND
VCC (+)	VCC (+)	VCC (+)

The operational work of the PAPU device is described in a block diagram, as shown in **Fig.3**, and it is placed above the skin. The user then selects the duration and intensity using the “Up”, “Down”, and “Set” buttons on the control unit. This control unit receives power from an adapter and activates the high-power light according to the chosen time and intensity settings. In addition, the control unit displays information such as the selected exposure duration, light intensity, and countdown timer. **Fig. 4** illustrates the flowchart of the device's operation. The user chooses the timer duration (15’, 30’, or 60’) and light intensity (50% or 100%) as needed. Once the selection is made, the device will operate according to the user's choice. After the selected time has elapsed, the light will turn OFF, and the light therapy process for pressure ulcer healing on the skin surface will be completed.

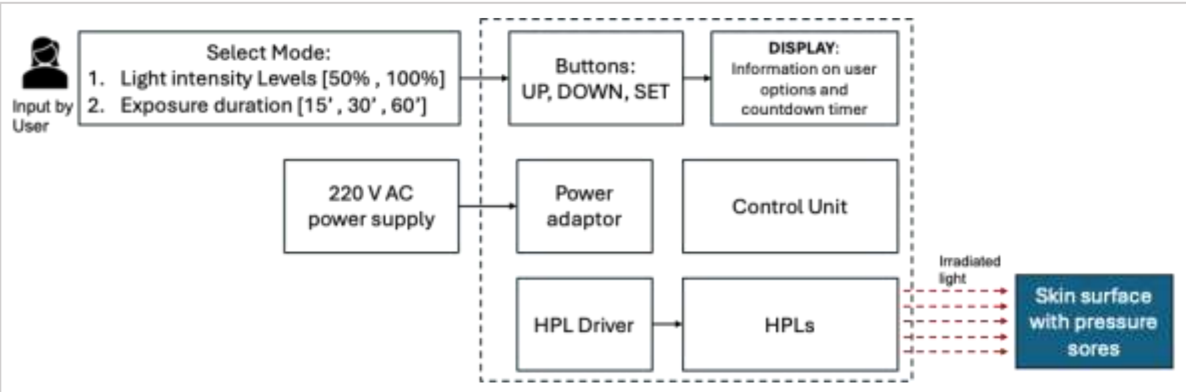


Fig. 3: Block diagram of PAPU system

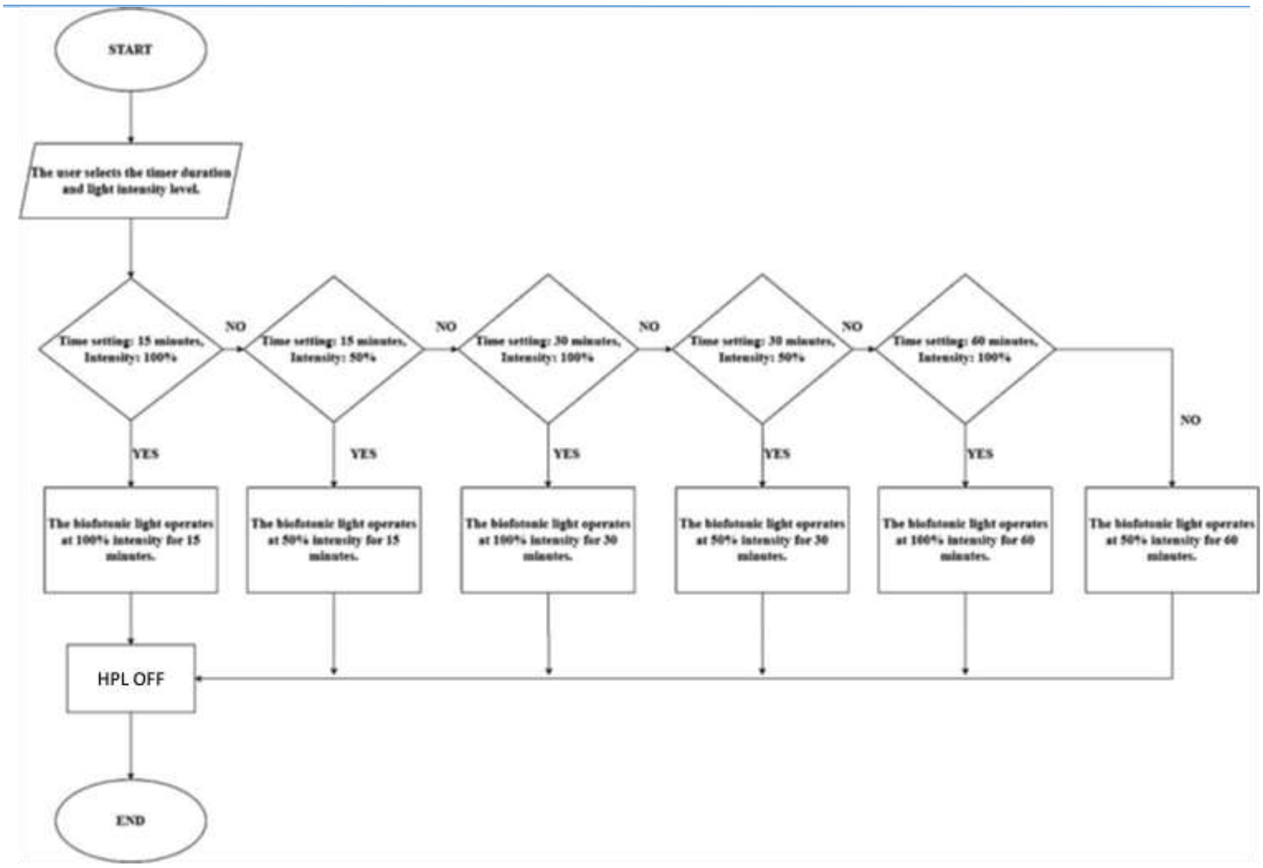


Fig. 4. Flowchart of the PAPU device operation

2.2. Experiments

This research used specific mice, which are usually used to test the performance of the PAPU device. In this experiment, four mice, as informed in **Table 4**, were used to observe the light treatment under the lamp at 30 cm, as shown in **Fig 5**, for seven days. Under the supervision of medical experts in the Faculty of Medicine laboratory at Universitas Padjajaran (Unpad), pressure ulcers were given to mice. They followed the code of ethics procedures approved by the Unpad Ethics Commission Board.

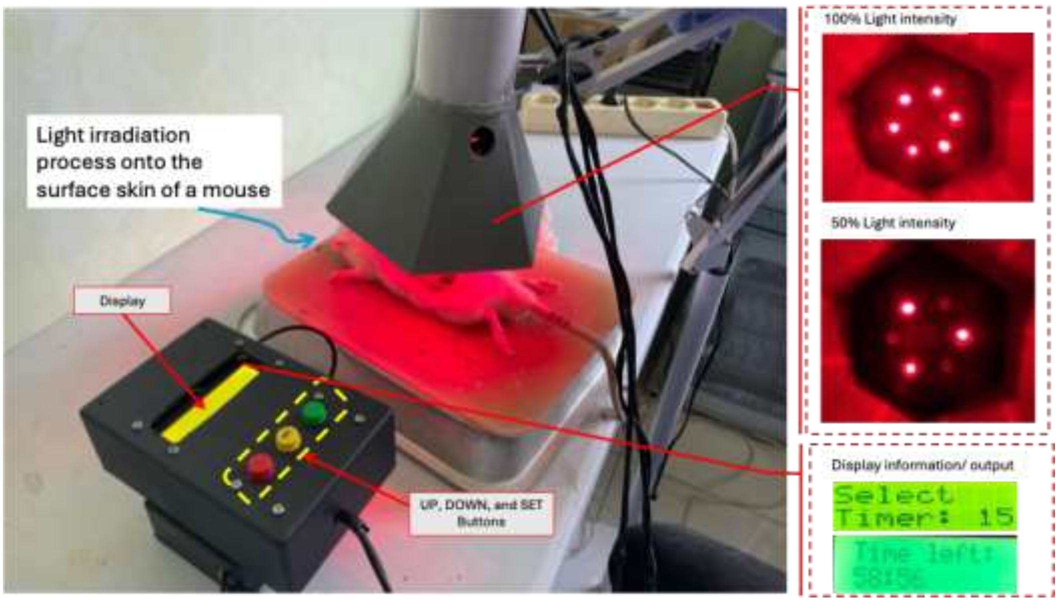


Fig. 5. The process of irradiating mouse using high-power LEDs

Table 4. Infographic of the experimental mouse

ID Number/ Name	Condition Description	Body Weight (g)
Mouse I-1	mouse subjected to artificial wounds by expert. not given any treatment or therapy for 7 days.	237
Mouse II-1	mouse subjected to artificial wounds by expert. It was given light therapy of PAPU once per day for 7 days. Its skin surface received 100% HPL light intensity irradiation for 60 minutes.	213
Mouse II-3	mouse subjected to artificial wounds by expert. It was given light therapy of PAPU once per day for 7 days. Its skin surface received 50% HPL light intensity irradiation for 60 minutes.	175

2.3. Digital Image Processing Technique

This research uses digital image processing techniques, i.e., resizing, RGB, and masking. Image resizing is the process of adjusting the size of an image, either by scaling it down or enlarging it. This technique is helpful in various image processing and machine learning tasks. Resizing is also essential for adapting images to specific size requirements, such as zooming in or fitting within dimensions. Overall, it plays a critical role in managing image data efficiently [16]. The RGB (Red, Green, Blue) technique is one of the most common color representations used in digital image processing. Each image has three primary color channels: red, green, and blue. These three primary colors can be combined with varying intensities to produce a broad spectrum. Each pixel in an RGB image has an intensity value for each color, with a general range from 0 to 255. The combination of these values determines the final color of the pixel. For example, if the value of R = 255, G = 0, and B = 0, the pixel will be red. But if the value of R = 255, G = 255, B = 255, the pixel will appear white. The RGB technique is often used for various applications such as color segmentation, filtering, image enhancement, and object recognition.

Fig. 6. Digital image processing technique used in this study to calculate the wound area

The procedure of digital image processing used in this study, as shown in **Fig. 6**, starts with pre-image processing, namely, resizing the image by focusing on the wound area. Next, the image is changed into Red-Green-Blue (RGB) format to perform the masking process on the red color produced based on the red color threshold as the wound area (the threshold used in this study is the one with a value greater than or equal to 127) [17], [18]. Masking is done to calculate the number of pixels in the masking area [18], [19].

3. Results and Discussion

To determine whether the PAPU system's performance follows the objectives, a series of component tests must be carried out first to ensure each part works appropriately. First, the button test must be used to select the HPL intensity mode used and the irradiation time. **Table 5** shows the button and display testing results, indicating that the system works properly. When pressed, the voltage and electric current that passes through the button shows optimal results, namely in the range of (4.6 - 4.7) volts and (4.4 – 4.8) mA.

Table 5. The test of the button and display of the PAPU device.

Button	Voltage (Volt) when the button is turned ON/ OFF		Current (mA) when the button is turned ON/ OFF	
	OFF	ON	OFF	ON
UP	0.20	4.70	0.15	4.60
DOWN	0.17	4.50	0.12	4.40
SET	0.19	4.60	0.14	4.80

To test the light intensity produced by a deep red high-power LED, testing was carried out using the AS803 lux meter, which has a measuring range of 1 to 200,000 lux, sampling rate 1.5 times/seconds, accuracy ±4%+10, and repeatability ±2%. This test was carried out indoors on 6 LEDs at 10 cm from the LED with a time interval of 10 minutes for 60 minutes. The selection of a measuring distance of 10 cm is adjusted to the needs of the light distribution area from the HPL light system to the object's surface to be illuminated. The test result of light intensity is shown in **Table 6**. The PAPU device, as shown in Fig.5, begins to work after the user selects the light intensity and the irradiation time is determined. The device's light will turn on and illuminate the surface of the mouse's skin for the time chosen, as also shown in Fig. 5. **Fig. 6** shows the observation pictures.

Table 6. The test of the intensity of the high-power LED of the PAPU device for 60 minutes

No	10-minute time interval to-	Light Intensity (Lm)
1	1	64
2	2	59
3	3	52
4	3	46
5	3	40
6	4	40
7	5	39

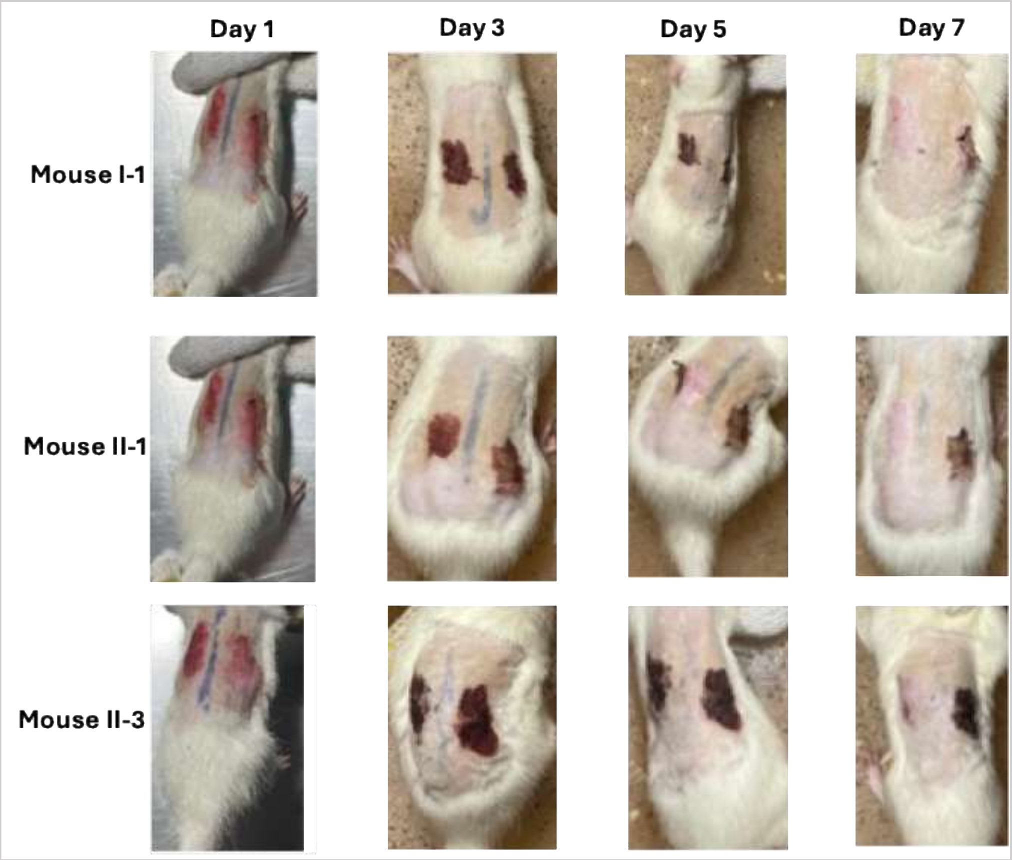


Fig. 6. Photographs of observation of 3 mice of a 7-day experiment as informed in Table 4

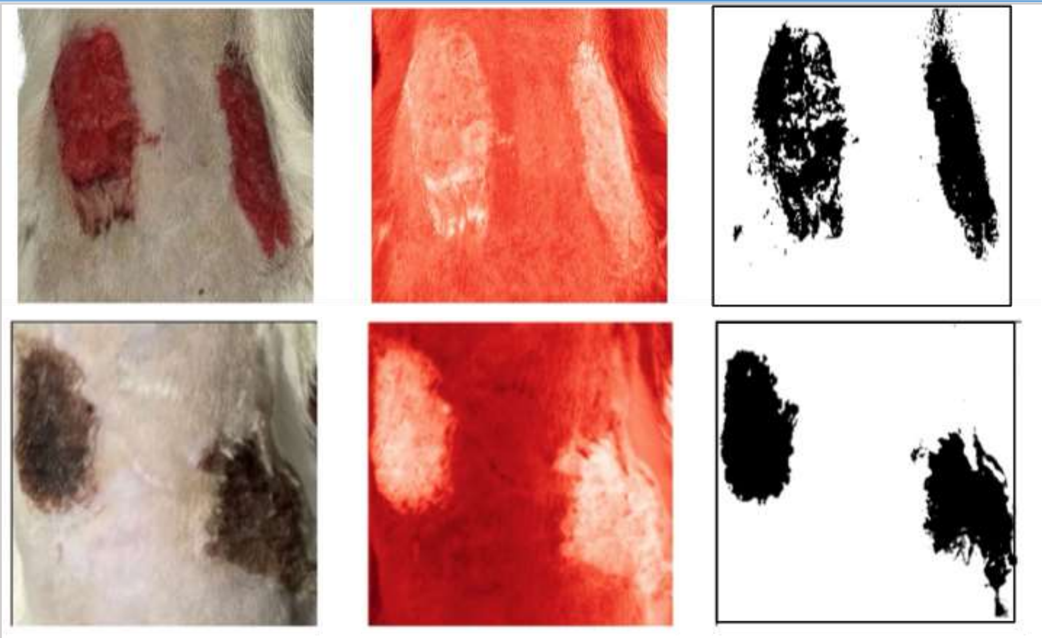
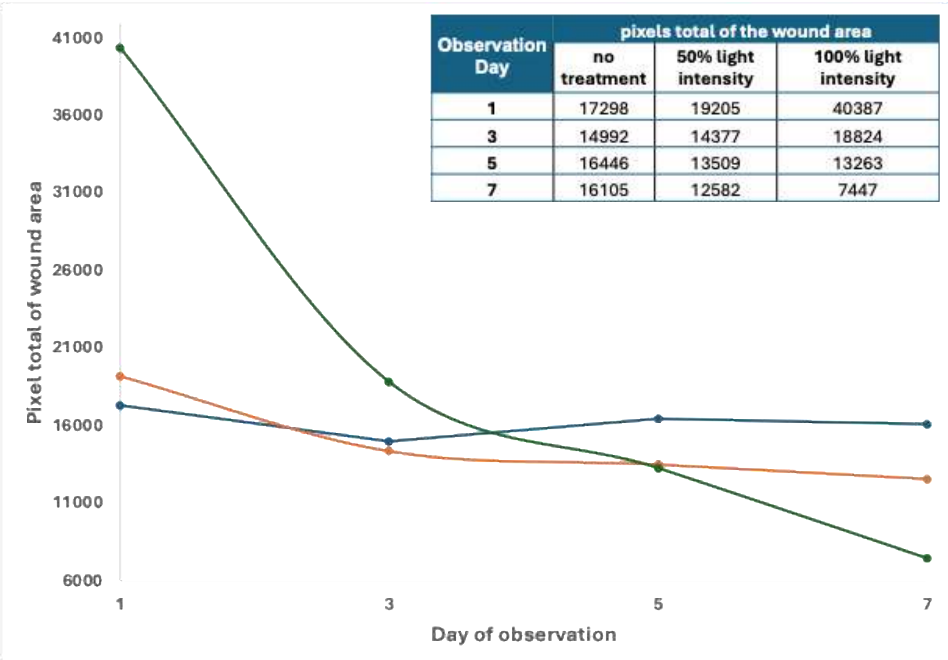


Fig. 7. Example of image processing implementation from resizing, RGB, to masking using group 2 mouse images with 50% light intensity treatment.



Observation Day	pixels total of the wound area		
	no treatment	50% light intensity	100% light intensity
1	17298	19205	40387
3	14992	14377	18824
5	16446	13509	13263
7	16105	12582	7447

Fig. 8. Graph of changes in wound area on the skin surface of the three experimental conditions in mice observed for seven days

In Fig.8, the graph of changes in pressure ulcers for seven days with 50% and 100% light-intensity treatment shows a consistent decrease in the wound area. This indicates a positive and consistent improvement or healing in pressure ulcers throughout the observation period. Next, by using the calculation formula for the equation as follows,

$$healing\ rate = \frac{Tp1 - Tp7}{Tp1} \times 100\%$$

where $Tp1$ is the total pixel area of wound day 1, and $Tp2$ is the total pixel area of wound day 2. The results of the rate of healing time around the wound in each mouse with no treatment, treatment with 50% light intensity, and with 100% light intensity, respectively, are 7%, 34%, and 82%. Thus, light irradiation onto the skin surface of mice with pressure ulcers using 100% HPL intensity for 60 minutes daily has accelerated wound healing. In addition, data in **Table 7** indicates that treatment using the PAPU device does not negatively affect mice's growth, especially their body weight.

Table 7. The final test of mice condition after applying artificial pressure sores onto their skin surface and with/without carrying out treatment with the PAPU device.

ID Number/ Name	Treatment Types	Body Weight (g)		
		Initial	Final	Difference
Mouse I-1	No treatment	237	245	8
Mouse II-1	50% HPL intensity for 60 min.	213	220	7
Mouse II-3	100% HPL intensity for 60 min.	175	181	7

4. Conclusion

This pilot study successfully demonstrated the potential of light therapy to accelerate the healing process of pressure ulcers. The experimental results on mice showed that light therapy using high-power LED deep red color with the wavelength of 660 nm, at 50% and 100% intensity, significantly improved wound healing, reducing healing time by 2-3 days compared to no treatment. These findings indicate that light therapy provides a promising therapeutic effect and can be further developed for broader applications in clinical settings. Future research could explore optimizing the parameters of light therapy, such as intensity, wavelength, and exposure duration, for the most effective wound healing. Moreover, developing a more portable and user-friendly device with real-time monitoring capabilities could enhance its practical use. The experimental aspects will be further explored through in-depth discussions with collaborating medical experts to ensure the best possible outcomes. Combining light therapy with conventional wound care techniques could also be investigated to maximize healing outcomes and broaden its applicability in various medical settings.

5. Abbreviations

ADC	Analogue to Digital Converter
LED	Light Emitting Diode
HPL	High Power LED

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