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Computer Aided Automatic Detection and Diagnosis System of Wound and Ulcer Care for Diabetic Patient

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Abstract*: *The diabetic wound healing process is a complex task under the category of B40 classification and below. The medical expenses are high in private wound specialist organizations compared to government hospitals. This article designed a computer-aided automatic detection and classification method for wound and ulcer care for diabetic patients using image processing techniques by Edge detection, colour scale of tissues, wound area calculation, and percentage calculation with GUI. The system results, Combination of edge detection methodology and 2-D boundary technique and design with the significant three tissues classification which is harmful and required immediate medical responses are Granulation, Fibrin and Necrotic values are used for wound area determination. The result of the system will help the patient immediately, which is classified as high or less severity.

Keywords*: *Automatic Detection, Colour Segmentation, Diabetic Wound Ulcer, Wound Image Analysis, Wound Management System.

I. INTRODUCTION

Insulin resistance is one of the most severe issues facing healthcare systems today, as well as a global public health hazard whose prevalence has grown substantially in recent years [1]. In diabetic patients, diabetic damage and ulcer formation is one of the most devastating consequences of the disease and is defined as a foot affected by ulceration associated with neuropathy or peripheral blood vessel disease of the lower appendage in a diabetic patient. The commonness of diabetic injury and foot ulceration in the diabetic populace is 4–10%; the condition is more successive in more seasoned patients. "It is assessed that about 5% of all patients with diabetes present with a background marked by wound arrangement and foot ulceration, while the lifetime hazard of diabetic patients fostering this difficulty is 15%" [2]. Diabetic foot ulcers are persistent lower limb wounds in people with diabetes with peripheral neuropathy. They are responsible for 85 percent of lower extremity amputations and are the most prevalent cause of lower extremity amputation in diabetics. The existence of a plantar foot ulcer, which may probe to the bone, allows for a clinical diagnosis to be made. MRI scans are essential in determining whether or not osteomyelitis is present and how severe it is. Treatment is determined by the size and thickness of the ulcer and the existence of concurrent infection. Clinicians often evaluate wounds by hand, using established scales and guides created on visual inspection to determine their severity. "Visual inspection is subjective and potentially inaccurate for wound area determination, and classification of tissue wound examination observations are not always recorded in a consistent format, and manual assessment of a patient's wound followed by a recording of findings adds to the amount of clinical work required to treat the patient's wound" [3]. Manual examination of a patient's wound and subsequent documentation of results adds to the burden of professional practice [4]. "The Wagner Classification System (sometimes referred to as Merritt-Wagner) was developed in the 1970s and comprised six ulcer grades, ranging from 0 to 5. This system evaluates ulcer depth and the presence of osteomyelitis or gangrene [5]. The grades are as shown in Figure 1.

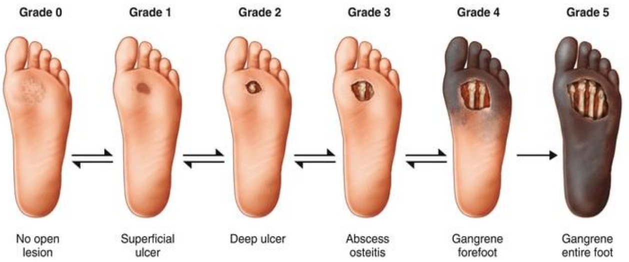

Fig. 1 Dysvascular foot breakdown-Natural history (Source: https://vitamindwiki.com/)

Based on computer vision techniques and standardizing wound evaluation, earlier studies [6]–[9] have established computer-aided methods to measure wound size and conduct tissue categorization to standardize wound assessment. All the results are standard ones not related to tissue classifications: Granulation, Fibrin, and Necrotic score.

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Using a GUI interface with MATLAB and three tissues classification values for wound area determination provides a new real-time wound evaluation system for wound clinics and patients. The primary goals were to make it easier to analyze foot ulcers images and develop precise yet computationally efficient algorithms for wound area measuring, wound tissue characterization, and the generation of a score for healing status evaluation.

In this paper, the automatic diabetic wound and ulcer detection and classification methodology is proposed using color segmentation, wound edge detection, percentage of wound area calculation, and tissue color spectrum as per the wound and ulcer images. Furthermore, the performance of the proposed detection system will analyze the wound or ulcer of diabetic patients in terms of classification severity, either less or high, using colour spectrum analysis. The proposed system will help the patients have a virtual doctor and closely watch their wound or ulcer in terms of daily healing and abnormalities detection. The severity level rate of the wound for “high” or “less” stages is verified by expert wound specialists.

II. EXISTING WORK

Reference [10] analyzed a recent review of measuring wound area analysis. If the wound surface area has not decreased by 50% or more after four weeks of conventional treatment, further therapeutic alternatives should be considered. There are several ways to measure wound surface area that differ in technology, precision, repeatability, and the amount of contact necessary with the patient's skin or the wound itself. Measuring wound area analysis is very important for the further treatment of diabetic patients.

Reference [11] developed an automated diagnostic method for continuous chronic wound condition monitoring that combined fuzzy c-means clustering with traditional computational learning algorithms for wound image segmentation. The author achieved a classification accuracy of 93.75 percent while categorizing the proportion of injured tissue in a segment region utilizing colour space implementations and the histogram sampling approach.

According to reference [12], chronic wound care management continues to be problematic in terms of an accurate wound size measurement, complete wound evaluation, timely wound healing monitoring, and effective wound care management. The author created a systematic method for the user-centred design and development of a novel intelligent mobile system for chronic wound care management that streamlines the nurse's job flow and satisfies the criteria for wound care of various types in clinics and hospital wards.

Based on reference [13], to determine the wound healing rate in diabetic foot ulcers, the noise in photos taken by digital cameras makes wound extraction difficult. The author presented a method based on deep learning (Convolutional Neural Networks) for precise wound area segmentation. The dataset utilized in the trials comprises high-resolution camera images of wounds by New York University. It contains 445 images, of which 392 are randomly chosen to train the algorithm. The trained model is then evaluated on a previously unknown test set of 53 pictures. The author acquired a high level of accuracy in segmentation and the Dice index. Reference [14] developed a label-free optical fluorescence imager that collects metabolic indices and noninvasively analyses the process of in vivo wound healing. Additionally, 3D optical cryo-imaging of the mitochondrial redox state was used to determine the injured tissue's volumetric redox status. There was a strong connection between the redox status and the wound area. The findings indicated that the innovative optical imaging technology might be successfully employed as a non-invasive optical indicator of the complicated wound healing process.

Reference [15] evaluated the accuracy of wound evaluation using the image processing HIS (Hue, Saturation, and Intensity) colour model. The accuracy of the colour evaluation was compared to doctors' estimations of necrotic tissue in digital pictures. The authors used a digital video camera to perform their suggested approach on real-time ulcer patients and got a 75% accuracy rate.

The most widely used automated assessment technique for diabetic foot ulcers is based on wound area measurement, colour segmentation, and healing score evaluation methods for determining the amount of slough in the diabetic wound illness. Numerous researchers, in particular, employed digital imagery as an input to neural network soft computing approaches throughout the evaluation process. There are no alternative techniques for calculating the size of a wound, such as using the tissue spectrum of colour. Our study effort successfully performed color tissue spectrum analysis, and professional doctors validated the results.

III. MATERIALS AND METHODS

This journal uses double-blind review process, which means that both the reviewer (s) and author (s) identities concealed from the reviewers, and vice versa, throughout the review process. All submitted manuscripts are reviewed by three reviewer one from India and rest two from overseas. There should be proper comments of the reviewers for the purpose of acceptance/ rejection. There should be minimum 01 to 02 week time window for it.

A. Materials

The wound pictures utilized in this study to evaluate the classification performance of diabetic ulcers were gathered from four distinct types of diabetic patients without knowing their current state of healing during three days. The collection contains wound recordings for patients undergoing long-term intracranial treatments at a hospital on Penang Island, Malaysia. These wound photos were taken using an Apple iPhone 6 at a standard distance and with all parameters.

B. Methods

The standard machine learning-based techniques for diabetic ulcer image categorization did not give information about the wound severity [10], [12]–[15]. As a result, a colour spectrum of tissue is necessary to determine the severity of wound ulcers [16], [17]. The purpose of this article is to establish a systematic technique for detecting wound severity levels based on granulation,

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fibrin, necrosis, foreign bodies, and the area of the slough in wound images utilizing a spectrum of colour tissues. The suggested approach entails edge recognition via several selection modes, colour segmentation via the colour spectrum, wound or ulcer area calculation, and categorization of severity as less or more by colour percentage computation. The suggested method for detecting and classifying diabetic wounds and ulcers using colour spectrum analysis is illustrated in Figure 2.

B. 1 *Wound Image Management System using GUI Interface*

The system was created using Graphical User Interface (GUI) design as a user-friendly idea. The demonstration is as follows:

Step 1: Once the patient is loaded, a user information input window similar to that shown in Figure 3 will display.

The user or patient should enter their name, date, blood glucose level, affected part temperature, and daily step count in the user data input box.

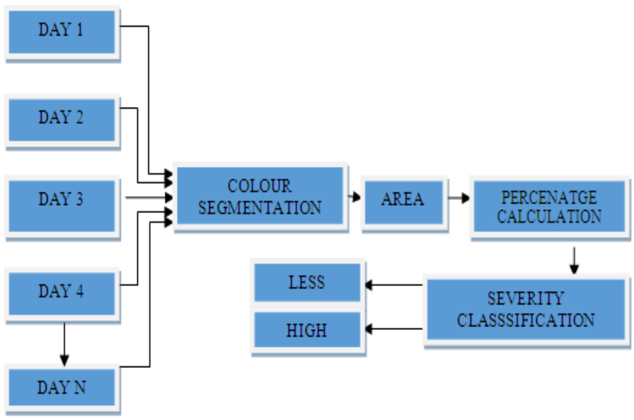

Fig. 2 Proposed wound severity classification level system using colour spectrum analysis

Step 2: Once the start push button is pressed, the "choose input picture" box displays as illustrated in Figure 3 to select an input image for analysis. The same type of camera is utilized with about the same imaging distance to produce accurate results that require many days of analysis for optimal output.

Step 3: Once the input picture has been selected, the edge detection window will display the original image, and the number of regions window will appear to accept user input.

Step 4: Single region mode enables analysis of the whole afflicted area or the unhealed portion of an ulcer or lesion. The dual region mode enables analysis of the unhealed portion of the afflicted area or numerous wounds present in the exact location. The picture analysis in single and double region mode depicted in Figure 3.

Step 5: Finally, the platform's command window will display the overall analysis result, including user information details, wound or ulcer analysis results, and input details comments with wound severity categorization.

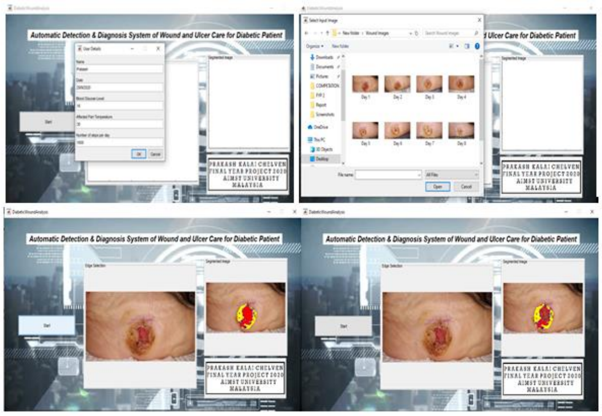

Fig.3 Screenshot of the graphical user interface

Fig.3 Screenshot of the graphical user interface used to provide wound pictures to physicians from patients. Clinicians should click the one-by-one message button as instructed to re-score all pictures with different patients and a varied number of days.

B.2 Marking Techniques- Edge Detection

Edge detection is used to pinpoint the specific element that requires analysis. The edge of the target region in the image can be determined using marking approaches. A marking cursor with several fixed points may be put on an uploaded image of a wound or ulcer to determine the right edge for analysis. The marking cursor is integrated into the system and is shown within the measuring system's internal GUI window. When in use, the marking cursor is brought into the optical field of view and utilized to bring a feature into touch with a technique for calculating the designated region. Contact with the feature has occurred when the centroid of a wound or ulcer is discovered. Once contact is established, the device automatically measures the wound or ulcer's pixels. Because the width of the lesion or ulcer is known, the tangent point at which it meets the part feature may be precisely calculated. Frequently, a marking cursor is ideal for measuring minute interior characteristics, such as grooved recesses within bores. The manual marking approach was chosen because its precision in determining the edge of the intended region was superior to other techniques.

B.3 *Colour Segmentation*

The method was developed with the primary three tissues classified as hazardous and requiring prompt medical attention in mind: Granulation, Fibrin, and Necrotic.

Granulation Tissue: Granulation tissue is the formation of new connective tissue and tiny blood vessels on the surface of a wound during the healing process. Granulation tissue grows from the wound's base and can fill wounds of practically any size.

Fibrin Tissue: Fibrinogen is transformed into fibrin, creating a cohesive network and providing temporary scaffolding for wound healing. The fibrin structural makeup and binding to cells and proteins play a significant role in wound healing. Slough is the term used to describe the yellow substance seen in the wound bed; it is often moist but dry. It often has a delicate texture.

It might be dense and adherent to the wound bed, thin and patchy, or all over the wound surface. It is composed of decomposing cells that collect in the wound exudate.

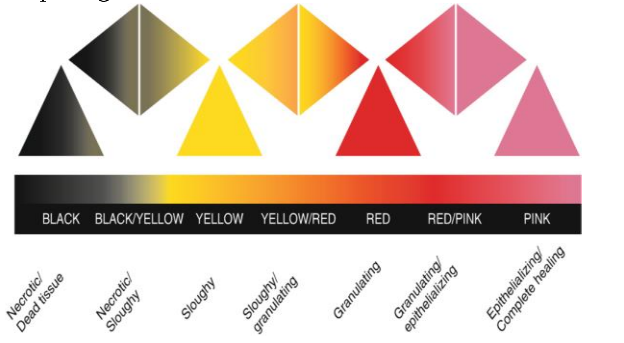

Fig.4 Spectrum of colours of tissues

Necrotic Tissue: Necrotic tissue has died or has become devitalized. This tissue is not salvageable and must be removed to wound healing.

The spectrum of colors approach was used to analyze the colours present in the user-uploaded picture, as shown in Figure 4. Each tissue detected on a wound or ulcer has its definition and state of health—the classification of the specific tissues that may be identified by the wound expert based on their appearance. The same approach was utilized to classify wounds using the masking technique. As a result, four distinct masking colours (RED-Granulation, YELLOW-Fibrin, BLACK-Necrotic, BLUE-Foreign bodies) were utilized to identify and categorize the wound or ulcer.

B.4 *Wound or ulcer area calculation*

The size of a wound or ulcer is critical for optimal wound or ulcer treatment. Monitoring changes in the region of the wound or ulcer enables evaluation of treatment efficacy and early diagnosis of stasis or worsening.

Step1: Pixels Quantification- A pixel or picture element is a physical point in a raster image or the smallest addressable element in an all-points-addressable display device in digital imaging. It is, therefore, the smallest controllable part of a picture shown on the screen. The specific pixels corresponding to the wound or ulcer were gathered and measured as the area was marked.

Step2: Pixels to mm^2 Conversion- To begin, determine the diagonal resolution in pixels and pixels per unit length using the equation 1 and 2:

$$dp = \sqrt{wp^2 + hp^2} \quad (1)$$

$$pixels\ per\ unit\ length = \frac{dp}{diagonal\ length\ of\ screen} \quad (2)$$

Where:

dp is diagonal resolution in pixels

wp is width resolution in pixels; here 512

hp is height resolution in pixels; here 1024

The diagonal length is measured in millimeters or centimeters, for example, a 1024*512-pixel screen. We can compute the size in pixels by utilizing the formula for the area of a given shape comparable to a circle.

Step3: Percentage Calculation (Wound or Ulcer Severity Classification) - The obtained data from the three-technique and methodology have been discussed above and accumulated on determining wound or ulcer severity classification by percentage calculation technique. The tissues detected using the colour segmentation technique had been pixel-masked. As a result, the pixels were utilized to compute the proportion of specific issues and the entire area of the wound or ulcer, as illustrated in equation 3:

$$\frac{Total\ pixels\ of\ granulation\ tissue\ (Red, Yellow, Black\ and\ Blue)}{Total\ area\ of\ wound\ or\ ulcer\ x\ 100\%} \quad (3)$$

The area calculation's correctness was validated using real-world material and a fixed parameter. The image recorded with the 20 cent coin is transmitted to the computer in its original quality, preserving the pixels' value and clarity. The area of an object may be quantified in terms of pixels by combining edge detection with colour segmentation. Thus, the total number of pixels gathered is translated to cm^2. As seen in Figure 5, the result displayed in the command window is as expected.

```
-----IMG_20201013_023956
Granulation: 0.00 %
Fibrin: 100.00 %
Necrosis: 22.97 %
Foreign Bodies: 0.00 %
Area: 4.41 cm^2
```

Fig. 5 Result displayed in the command window

The area of the coin calculated as below,

Coin area = πr^2 (4)

Where r is the radius of the coin

$= \pi\ (2.359/2)^2 = 4.37\ cm^2$

Therefore, the output result obtained from the analysis of the coin area by using the system is 4.41 cm^2 as shown in Figure 3 and calculating the efficiency as below,

Area accuracy = (Real area / computing area) X 100 %(5)

= (4.37 / 4.41) X 100 %

= 0.9909 X 100 %

=99.09 %,

The accuracy value obtained satisfies the requirement and the testimonial method had been declaring as successful. By referring to a wound severity classification [18], the calculated proportion of each tissue was utilized to determine the wound severity classification in terms of high or low as shown in Table I.

Table- I: Wound or Ulcer Severity Classification

Wound or Ulcer severity classification					
No	Tissues type	Percentage	Percentage	Level of severity	
1	Granulation	< 50% of overall area	> 50% of overall area	Less	High
2	Fibrin	< 30% of overall area	> 30% of overall area		
3	Necrotic	< 25% of overall area	> 25% of overall area		

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IV. RESULTS AND DISCUSSIONS

All four procedures, including edge detection, colour segmentation, wound or ulcer area calculation, and percentage calculation, have been finished. The anticipated outcome was obtained by using all four of the methodologies results are discussed below.

A. Edge Detection

The first procedure is edge detection, which was accomplished using a hand marking approach as there are no optimum ways, as each project requires a unique strategy. By including resolution and contrast into the picture, sure edges become more visible in lab colours following grayscale conversion. Several more approaches have been evaluated, including the Sobel, Canny, and fuzzy logic methods and the colour threshold of red, green, and blue techniques, which are more sensitive to picture noise. Manual marking produces better outcomes than the trial and error approach.

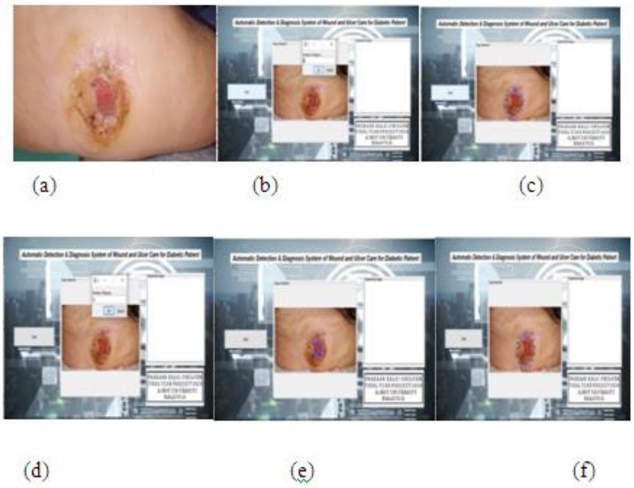

Fig. 6 Edge detection techniques (a) Original image (b) Input window of single region selection mode (c) Input marking of single region selection mode (d) Input window of multiple region selection mode (e) Mode 1 input window of multiple region selection mode (f) Mode 2 input window of multiple region selection mode.

As seen in Figure 6 (a), which is the original input picture, two distinct edges are visible on the image. The single region selection mode enables analysis of the chosen section of the wound or ulcer using one of two variations: the unhealed portion of the wound or ulcer or the entire affected component. Figure 6(b) shows that when the system starts and the required number of areas is selected, an option window displays to accept user input. To continue in single area selection mode, enter "1". As a result, the "OK" push button was activated, enabling the marking cursor on the input picture. The region to be evaluated should be accurately designated to provide a high-efficiency and accurate outcome, as seen in Figure 6 (c).

The multiple region selection options enable an analysis of the chosen component of the wound in two configurations: healed wound or ulcer portion or several wounds or ulcer portions at the same time. Figure 6 (d) shows the desired number of regions the option window displays when the system accepts user input. As seen in Figure 6(e) and Figure 6(f), when the multiple region selection modes are selected with the value "2", the marking cursor appears twice to mark the regions. This option enables the user to analyze the healed section of a lesion or ulcer that has been previously identified. For both region selection modes, the marking approach is implemented so that a "+" sign appears on the edge detection window to initiate the marking process. The principle is quite similar to the intelligent scope, commonly used in industry to determine component specifications. Once the entire desired part has been marked, the "O" symbol appears on the pointer, which may be double-clicked to finish the selection.

B. Colour Segementation

The second procedure is colour segmentation, which is accomplished using the Spectrum of a colour algorithm. This procedure demonstrates how to separate colours using a lab colour space and K-means clustering—reading a picture of a wound using the same approach as that used to determine the presence of Hematoxylin and Eosin stain. Hematoxylin and eosin stain is a major tissue stain used in histology and is the most often used stain in medical diagnosis. The same principle was used to wound picture clustering, where blue masking was utilized to identify Hematoxylin and Eosin stains, and therefore a masking technique was employed to cluster wound images.

According to the observation in Figure 7(a), the image has a variety of hues, including red, yellow, pink, and grey. Utilizing a colour segmentation masking approach makes it possible to quantify visual differences in terms of pixels. Clustering is a technique for categorizing items, and each item is treated as though it has a position space using the masking approach. It identifies divisions that keep things inside each cluster as near to one another as feasible while keeping them as far apart as possible from objects in the other cluster. The minimum number of clusters must be provided and a distance measure to quantify. This project made use of four clusters. The cluster is yellow, red, black, and blue in hue

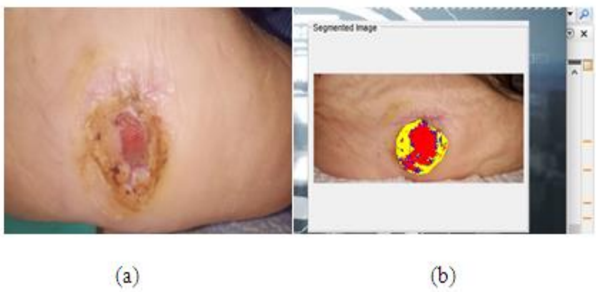

Fig 7. Process of colour segmentation (a) Original Image (b) Image labelled by cluster image

C. *Wound Severity Classification*

As seen in Figure 7 (b), the tissues were masked according to the hue of the pixels in the picture. The specific masking colour applies to all types of variation in the colours of pixels. For instance, if a yellow mask is applied, any pixels containing light yellow, dark yellow, or any other shade of yellow will be tallied as yellow pixels.

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The masking approach can achieve a 100 percent marked part of the image without omitting any tissue included in the input image. Apart from the three principal tissues, granulation, fibrin, and necrotic tissue, blue masking was utilized to guarantee that pixels other than red, yellow, and black were also marked to boost the system's effectiveness. A combination of edge detection methodology and 2-D boundary techniques is used to calculate wound area and classify tissues in terms of colours and compare the area to compute wound percentage and wound severity. Table II shows the severity level of the wound as per the colour segmentation process using Table I.

V. CONCLUSION

The management of diabetic foot ulcers is a significant therapeutic issue, necessitating an immediate assessment of tactics and therapies to meet goals and minimize the most efficiently and cost-effectively possible burden of care. As illustrated in the "Findings" section, our approach for determining the wound border generates clinically accurate results. The average overall computing time for the method for determining the wound border, colour segmentation, and calculating the healing score, when implemented on an i5 CPU (Intel i5 2.5 GHz), is around 5 seconds for photos. The system demonstrates that our wound analysis approach is sufficiently time-efficient for real-time wound evaluation. The severity level rate of the wound for "high" or "less" stages is verified by an expert wound specialist.

Table – II: Wound Severity Classification

Patient.	Input Image	Segmented Image	Results in %					Severity level
			Granulation	Fibrin	Necrosis	Foreign Bodies	Area in cm^2	
1	 Day 1 Day 2 Day 3		99.68	0.03	0.00	0.29	1.38	Less
			99.27	0.32	0.00	0.41	1.27	
			97.11	1.25	0.00	1.64	1.88	
2	 Day 1 Day 2 Day 3		99.00	0.49	0.00	0.51	1.23	Less
			94.73	4.57	0.00	0.70	0.81	
			91.03	4.99	0.00	3.98	1.08	
3	 Day 1 Day 2 Day 3		97.64	1.13	0.00	1.23	0.83	Less
			83.93	13.56	0.00	2.51	0.61	
			99.79	0.02	0.00	0.19	0.52	
4	 Day 1 Day 2 Day 3		13.59	60.83	0.00	25.58	2.78	High
			31.71	61.82	0.00	6.46	2.18	
			99.18	0.20	0.00	0.62	0.53	Less

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AUTHORS PROFILE

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