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| RESEARCH ARTICLE

Visualizing Wound Healing: Integrating Clinical Imaging with Nursing Practices for Enhanced Outcomes

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| ABSTRACT

Wound healing (WH) is an extraordinary biological process that encompasses the management of injuries, tissue repair, and the restoration of the integrity of the skin and surrounding tissues. This process plays a crucial role as a defensive barrier, preventing infections and injuries and maintaining homeostasis. A normal wound progresses through a series of stages, including hemostasis, inflammation, proliferation, and remodeling, within a specific timeframe. This type of wound is known as an acute wound. However, when the healing process is delayed or interrupted at any stage, the wound becomes chronic. Several factors can influence WH, such as physiological factors like age, gender, and oxygen levels; pathological conditions such as diabetes, cancer, and obesity; and lifestyle factors including poor hygiene, smoking, and alcohol consumption. If a chronic wound is not properly managed, it can lead to further complications, such as an increased risk of infection, higher morbidity, and even mortality. The role of healthcare, particularly the nurse, in wound care is to monitor the case, handle it, and reduce complications. Therefore, it is essential to optimize nursing practices and ensure adherence to guidelines, keeping up with their continuous updates. Visualizing WH is a crucial aspect of wound care, enabling effective monitoring and evaluation of the healing process. This review explores the theoretical perspectives and practical applications of clinical imaging in wound assessment. Techniques such as 3D scanning, ultrasound imaging, and visual documentation are highlighted for their role in tracking wound characteristics, diagnosing complications, and guiding treatment plans. Emphasis is placed on integrating advanced technologies with nursing practices to enhance patient outcomes. By combining theoretical frameworks with innovative imaging methods, this study underscores the importance of visual tools in improving the understanding and management of WH.

| KEYWORDS

Wound healing, nursing, clinical imaging, 3D scanning, ultrasonography

| ARTICLE INFORMATION

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1. Introduction

The word "wound" often describes the damage to the epithelial tissue's anatomy conveyed by any type of violence, disease, or other external aspects [1]. Wound healing (WH) is a complicated physiological pragmatism encompassing stages like immediate haemostasias, inflammation, proliferation, and remodeling. In this process, several cascade reactions happen to achieve appropriate healing by endorsing tissue restoration and regeneration [2]. The fundamental purpose of the WH process is to restore the usual skin anatomy, integrity, function, and performance within the time frame. If the wounds cannot be healed normally or are delayed they will be susceptible to contamination resulting in chronic wounds [3]. Major risk factors that impact the transformation of acute wounds into chronic wounds involve infections, diabetes mellitus, uncontrolled overweight, and peripheral vascular disease [4].

When patients are prepared for wound care, nurses, in teamwork with other colleagues of the health care staff, observe and manage the factors that surround the patients to provide an ideal healing circumstances [5]. Nursing experts have the major responsibility in wound care confirmed on the recent and best quality data existed. They must preserve their wound skill by surveying the latest instructions and guidelines in the wound care research field [6]. The wound care roles of an expert nurse are changing the dressing, controlling wound contamination, hygiene, promoting nutrition, training, and patient comfort. Finally, expert nurses should also focus on avoiding hypertrophic scars and keloids [7,8].

Medical imaging is an advanced form of healthcare that helps doctors make early and correct diagnoses and classify injuries and all types of health issues [9]. Medical imaging possesses faster and highly reliable data, significantly better patient outcomes, and assists doctors to achieve an accurate decision. Imaging supports physicians to determine the medical case progression or stage of an injury. This data improves clinicians achieve the best treatment approach [10]. noninvasive imaging is accepted to most doctors involving X-rays, CT, and MRI as examples. Some are becoming aware to those supporting wound care. Photography has become an essential step of the medical record of wound care course [11]. Nevertheless, the field of imaging technique is just developing within wound care, giving more advanced diagnostic equipment [10]. Medical imaging was used as a key device for several years ago in the medical field. In past, doctors were unable to access such technique for wound care in the wound care clinics but now a new trend of portable developed wound care instrument which can simply applicable into algorithm of the wound care for diagnosis and monitor wound development [11]. Wound evaluation depends mainly on visual monitoring by physicians. This evaluation is basically subjective and gives the chance for innovation of novel tools to eliminate subjectivity from the evaluation procedure. Advanced devising for digital photo has been arisen by using smart phones linked with advanced machine learning application [12]. But the medical image depends on some conditions such as lighting, space for the patient, and quality of camera [10].

The aim of the present review article is to explore the mechanisms of WH, examining the critical roles of expert nursing in WH process, and provide clinical insights through imaging.

2. Search strategy

The literature review was conducted using the following databases: PubMed, SpringerLink, Google Scholar, Dar AlMandumah, Egyptian Knowledge Bank (EKB), Saudi Digital Library (SDL), ResearchGate, BioMed Central, ScienceDirect, and Scopus. The search was restricted to English-language papers. The following keywords were used: “acute wounds,” “chronic wounds,” “nursing,” “wound healing,” and “clinical imaging.” The review includes a variety of articles, including original research, review articles, viewpoints, and opinion pieces. The literature search spanned from inception through to 2025, ensuring a comprehensive examination of both foundational and current studies.

3. Overview of WH Stages and Risk Factors involved

3.1 Stages of WH Process

A series of coordinated biological events is involved in WH process to restore tissue integrity and function. The process begins immediately after an injury and progresses through several overlapping phases: haemostasis, inflammation, proliferation, and remodeling (Fig. 1). Each phase plays a crucial role in repairing damaged tissue, and any disruption can lead to chronic or delayed healing.

The earliest stage of WH process, haemostasis (lasting from minutes to hours), occurs immediately after an injury. During this stage, blood vessels underwent vasospasm, and platelets undergo modifications, adhesion and aggregation at wound site [13]. Platelet modifications are regulated by the interaction of platelets with the von Willebrand factor, which triggers alterations in platelets shape and enhances their ability to interact with the wound environment. Modified platelets secret substances such as ADP, thromboxane A2, and growth factors. ADP activates additional platelets through positive feedback, while thromboxane A2, secreted by the activated platelets through cascade reactions, promotes further platelets activation and vasospasm to minimize blood loss [14,15]. Aggregated platelets form the “white clot” through the binding of fibrinogen (leaked from platelet alpha granules) to modified glycoprotein receptors on the platelet’s surfaces [16,17]. The interaction is critical for stabilizing the clot and initiating the subsequent phases of WH. All steps of this stage contribute to forming a fibrin mesh (final product) that serves as a basic for inflammatory cells, such as neutrophils and macrophages, to migrate [18]. The migration transitions the process to the next phase, known as the inflammatory stage.

Inflammatory stage, which lasts from one to three days, is the second phase of WH process. The immune cells in the injured tissue secrete prostaglandins and cytokines, which endorses inflammatory reactions, increase the adhesion particles, elicit inflammatory cells, enhance blood vessels permeability to allow the leakage of inflammatory cells into the wound site [19]. The first inflammatory cells to arrive at the site are neutrophils which engulf tissue debris and pathogens through a biological process called phagocytosis [20]. Macrophages, the most critical phagocytic cell in the delayed inflammatory response, play a pivotal role by stimulating fibroblasts at the injury site and promoting the extracellular matrix (ECM) bio-formation to create a new scaffold for tissue repair [20,21].

The proliferation stage, which lasts from a few days to a month, is the third phase of the WH process. This stage is divided into three key steps: angiogenesis, granulation, and re-epithelialization [22]. Angiogenesis is a critical step in WH process, during where

specific cytokines, tumor necrosis factor-α, and growth factors such as transforming growth factor-β and vascular endothelial growth factors triggers the biosynthesis of new blood vessel network. The granulation step involved activated platelets attracting fibroblasts to the wound site, leading to the formation of granulated tissue and the connective matrix [23]. This matrix contains adhesive proteins and fibrous proteins, including collagen III and elastin, and is crucial for the biosynthesis of a new ECM [24]. Re-epithelialization occurs when surrounding keratinocytes accelerate the repair process by dividing and migrating across the destructed area to reestablish the skin barrier function [22].

Remodeling stage is the last phase of the WH process. The cornerstone cell in this stage is the myofibroblasts, which play a critical role in tissue remodeling [25]. These cells secrets matrix metalloproteinases (MMP) and their inhibitors in balance Mannar. MMP are responsible for the gradual substitution of collagen III in the granulation tissue with collagen I, resulting in the formation of scar tissue [22]. At the conclusion of this stage, the myofibroblasts underwent apoptosis. During this time, phagocytic role of macrophages becomes prominent once again, as they clear cellular debris and deadly cells, completing the tissue repair process [26].

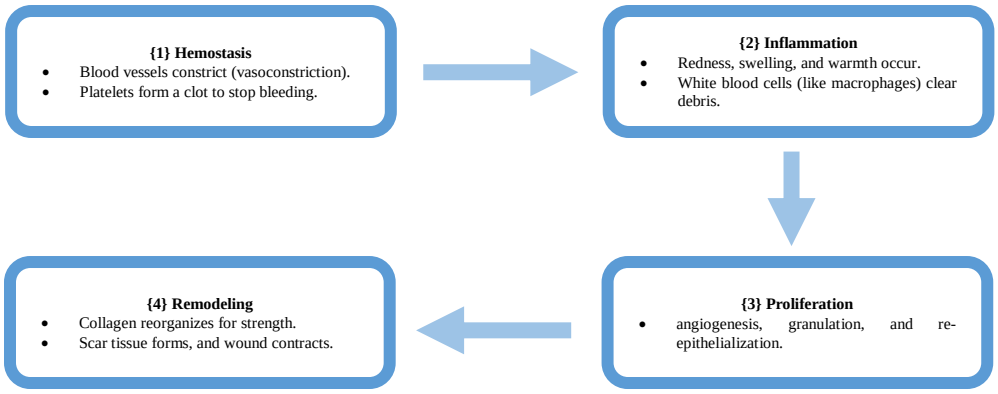

Fig. 2 A diagram represent the WH stages.

3.2 Key Factors Influencing Healing

The exact time course and result of WH process will be determined by the nature of wound—its location, dimensions, and type [27,28]. A combination of other factors can contribute to failure in the WH process. In general, the issues affecting injury restoration can be classified into local and systemic factors [29]. Local factors specifically alter injury characteristics and include oxygenation, infection, foreign bodies, and venous insufficiency [28,30]. Systemic factors, on the other hand, affect the body's overall capacity to recover. These include age, gender, sex hormones, stress, ischemia, and diseases such as diabetes, keloids, fibrosis, hereditary healing disorders, jaundice, and uremia. Other systemic factors include obesity, medications (e.g., glucocorticoid steroids, non-steroidal anti-inflammatory drugs, chemotherapy), alcoholism, smoking, immunocompromised conditions (e.g., cancer, radiation therapy, AIDS), and nutritional deficiencies [28-30].

3.3 Acute and chronic wounds

Wounds can be classified into two types: acute and chronic. Acute wounds are traumatic or surgical injuries that heal normally within a standard timeframe. In this wound, structural cells, immune cells, and biochemical substances coordinate with each other's in regular manner to achieve the healing process [31,32]. But chronic wounds, on the other hand, are injuries that do not heal in the usual sequence of stages and take an extended period to heal. Common characters of chronic wounds are frequent infection, exudation of fluid, oxidative stress, tissue necrosis, diminished angiogenesis, and faulty re-epithelization [33,34]. Diabetic foot ulcers, vascular ulcers, arterial ulcers, burn ulcers, pressure ulcers, malignant ulcers, traumatic ulcers are categorized as chronic wounds (Fig. 2) [35]. They are commonly noticed in old persons suffering from diseases, such as diabetes mellitus, vascular issues and obesity [32,36]. Diabetes alter all four stages in skin wound repair [37]. Intrinsically, diabetic ulcers are accompanying with an extreme efflux of inflammatory mediators, and decreased biosynthesis of healing intermediates. In this case, immune response leads to the enhancement of pro-inflammatory macrophages (M1 phenotype), which influences to the damage of tissue and results in necrosis (cell death) [32,38].

Over time, there has been a growing resistance to antibiotics frequently used to treat chronic wounds [39]. The rising incidence of resistant micro-organisms has made it more challenging to select successful antibiotics for chronic injury infections. By studying the complexities involved in monitoring chronic wounds and handle them effectively, it is possible to achieve better results, involving recovered patient quality of life, diminished sickness and death, and lower healthcare expenses [40].

Fig. 2 Different types of chronic wounds. (A), (B), (C) diabetic foot ulcer; (D), (E) Thermal burn ulcer; (F), (G) pressure ulcer; (H) arterial; (I) Malignant ulcer; (J) traumatic ulcer.

3.4 Nursing and wound care

Chronic wound management should be carried out by a professional team to meet the needs of patients with chronic wounds [41]. Wound care is a branch of healthcare that focuses on the assessment and monitoring of wounds. Wound care encompasses both the evaluation and treatment of wounds. The assessment process involves evaluating various factors such as the condition of the wound bed, the size of the wound, potential infection, and the type of tissue present. Wound management, on the other hand, focuses on actions like cleaning or debriding the wound, as well as applying wound care products, including dressings. In a broader sense, wound care also involves addressing the patient's pain, providing education on proper care techniques, and ensuring nutritional support to promote healing [42,43]. Chronic wounds must be properly identified to help both patients and healthcare specialists understand the main cause, prognosis, and handling options. In some regions, Doctors responsible for wound diagnosis [44], but in another regions, nurse specialists and experienced clinical nurses are also authorized to diagnose wounds [45]. Whether the wound is acute or chronic does not affect the method of wound care. However, in the case of chronic wounds, proper assessment is crucial for treating the underlying causes that led the wound to reach this state [41]. Wound and ulcer avoidance involves all nursing professionals' approaches when managing the patient's care. Nurses are responsible for monitoring wounds using evidence-based interventions, and collaboration with patients, their relatives, and healthcare team is essential to achieving this objective. The goal is to preserve the integrity of all skin layers when a wound is preventable, or to avoid an acute wound from progressing into a chronic wound. A thorough understanding of the factors that influence WH and the causes that contribute to chronic wound progression is essential for preventing ulcers [46,47]. For example, smoking may alter the WH in both types of wounds. Patients who may have a clinical condition like diabetes may delay the healing process [41].

Skilled and experienced wound care nurses play a crucial role in wound care and prevention by staying up to date with the latest papers and guidelines on wound management. Nurses have traditionally been responsible for tasks like changing dressings and preventing wound infections. However, their role extends beyond these duties to include interventions such as promoting proper nutrition, encouraging physical activity, providing psychological support, and ensuring hygiene and comfort. Additionally, at the conclusion of the WH process, nurses play a key role in preventing the development of keloids and hypertrophic scars [48,49].

The nurses' responsibilities in wound care vary across countries and depend on the level of education. This text emphasizes the roles of registered nurses in wound care, which generally include tasks like wound assessment, local wound care, and educating patients. However, they do not involve prescribing medications, diagnosing wounds, or performing surgical treatments. Nurses play a vital role in wound prevention in various settings, from home care to specialized healthcare facilities. The primary aim of prevention is to maintain intact skin. This requires understanding the risk factors and mechanisms that lead to wound development, as wounds are often invisible in the early stages. If a preventable wound becomes visible, it signals a failure of preventive measures, transitioning the focus to wound management. Preventive strategies remain essential to avoid further wounds or ulcers. Wounds and ulcers can lead to severe complications, including infections and sepsis. Effective prevention and management are critical for improving quality of life and minimizing healthcare costs by reducing incidents like pressure ulcers and other related injuries [50,51].

Pressure wounds are mainly avoidable, and all efforts and understanding of avoidance approaches must be applied and managed in daily practice. Pressure wounds are uncomfortable, growth the possibility of infection, delay treatment, increase death and are expensive [52-54]. Expertise and management of nursing professionals towards avoiding pressure wound are key success factors [55,56]. Nursing professionals should rely on guidelines and consensus documents to inform their practice. Resources like the Prevention and Treatment of Pressure Ulcers/Injuries: Clinical Practice Guideline and the Practical Guidelines on the Prevention and Management of Diabetic Foot Disease provide essential tools for daily care [54,57]. Alongside international guidelines, national guidelines focus on evidence-based practices tailored to local implementation. Accurate wound diagnosis is crucial, as conditions

like moisture-associated dermatitis can be mistaken for pressure ulcers or other skin lesions. Chronic wounds and skin tears may resemble one another or co-occur, complicating diagnosis. Therefore, nurses must understand the aetiology and pathophysiology of various wounds and ulcers. Staying updated on the latest evidence-based practices and research is essential for effective wound care. Prevention and treatment require multidisciplinary collaboration, integrating patient perspectives and involving family members. This teamwork improves prevention strategies, care delivery, and outcomes [58].

3.5 Clinical Imaging in WH

Clinical observations of wounds can assist in monitoring wound characteristics, such as shape and volume, as well as their response to therapy [59].

3.6 Two-dimensional (2D) photographs

Medical techniques have principally applied 2D photos for evaluating wounds [60]. The estimation of wounds is based on two categories of measurements: optical inspection and spatial examinations. The optical inspection requires analyzing aspects such as dimension, texture, color, and severity. The approaches for spatial examination cover assessing wound location. Wound segmentation in 2D can be performed using a range of techniques, including K-means clustering, deep convolutional neural approach, k-nearest neighbors, ...etc. Other techniques include superpixel region-growing algorithms, color histograms, and the application of geometric and optical features of the wound shape to facilitate wound segmentation [61]. However, deep convolutional neural approach remains the most widely used techniques in this field. A specific deep neural technique can recognize the area of the wound, discrete it from the disturbing background, and detect its location. Therefore, it creates a highly reproducible map without operator help and normalizes photo acquisition during analysis [62]. The output of the neural network model formed a segmented grayscale wound photo as a result. Successively, this photo undergoes a series of post-processing phases, containing thresholding to produce an early binary photo, hole filling, and the exclusion of minor zones. These phases integrated in the creation of a complete binary photo [63].

3.7 Planimetric evaluations

The approach for assessing wound area *via* digital photographs supported with planimetric software is preferred because of its naivety and inexpensive. In this technique, an image of the wound is captured with a ruler or known-size indicator placed along the wound's boundary. The photo is then transmitted to a computer with planimetric software. The indicator or ruler act as a source for measuring the linear geometry within the photo. After following the wound edge manually, that software analyses and shows the wound's zone in pixels then converted cm^2 [64]. It's fundamental to accommodate the space between the camera and the analyzed wound perfectly. This approach can give a perfect photo for irregularly wounds [65].

3.8 Three-dimensional (3D) scanning

Various 3D wound evaluation tools have been improved. These incorporate laser scanning devices, approaches rely on structured light, digital imaging systems, and instruments using stereophotogrammetry machinery. These tools can estimate WH from a volumetric viewpoint. The 3D scanning approach plays a significant role in monitoring wounds in severe cases, such as injuries and burns, as well as in evaluating scars. Earlier examinations needed the employment of 2/3 cameras alongside taking photos of the scar to create 3D records. But they are not significantly applied in clinical situations due to respective practical restrictions, such as uncertainty, high cost, time-consumed techniques, and complications in operation [60,66]. Laser scanning devices are frequently employed for 3D reconstruction. This tool is frequently applied to make labelled and colored 3D reconstructions. Laser scanning technique principle is combination of laser machinery and RGB cameras [63].

3.9 Ultrasonography

Ultrasonography offers multiple advantages such as speed, inexpensive, radiation-free, non-invasive, and its ability to provide deep visualization up to 10 cm through soft tissues [67]. Ultrasound scanning can assess the principal features for evaluating WH such as injure geometry, blood flow, and mapping of tissues elasticity [68]. Moreover, ultrasound has been proved as a trustworthy technique for determining wound dimension, a diagnostic factor in following the changes in WH over time. The mechanism of this approach is that ultrasound allows the identification of biological tissue properties by investigating acoustic feature like rate, decrease, absorption, and tissue diffusion of the beam. For infection avoidance, a disposable plastic sheet was put on the probe before examination. During ultrasound imaging, videos were monitored with the probe instructed both diagonally and longitudinally. The probe was transferred from the healthy zone to the wound zone by moving around the injury. Successively, the image taken from the videos appeared the wound [69].

4. Conclusion

Wound healing is a physiological process that normally occurs following any injury. This process consists of four stages to restore the anatomy and integrity of the tissue. If the wound responds to the healing process spontaneously within the expected timeframe, it is called an acute wound. However, if the process is delayed or the wound remains unhealed, it becomes a chronic

wound. Many factors can affect the healing process, such as age, gender, smoking, alcohol consumption, or health disorders like diabetes and cancer. Nurses play a pivotal role in wound care, helping to prevent wounds from becoming chronic or reducing their progression by understanding the patient's history and the risk factors affecting healing. Nurses must stay updated with the latest research in this field to ensure optimal outcomes. Visualizing images is a vital tool in wound identification and management, aiding in determining the most effective treatment strategies. Clinical observations, combined with advancements in imaging techniques, provide comprehensive tools for wound assessment. While 2D photographs and planimetric software offer cost-effective and accessible methods for evaluating wound dimensions and characteristics, emerging 3D scanning and ultrasonography techniques enhance precision by capturing volumetric data and deep tissue visualization. These methodologies collectively support accurate monitoring of wound healing and therapeutic outcomes, with deep convolutional neural networks leading in automated segmentation and analysis.

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