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SMART WEARABLE SENSORS INTEGRATED WITH WOUND DRESSING TO HEAL CHRONIC WOUNDS

N.P.Swetha Menon [a,b], M. Anish Sharmila [b*], P. Priyanka [c], S.Vidhyavathi [a]
[a] *Department of Fashion Designing, Faculty of Science and Humanities, SRM Institute of Science and Technology -Ramapuram Campus, Chennai- 600089, Tamil Nadu, India*
[b] *Department of Fashion Design and Arts, Hindustan Institute of Technology and Science, (Deemed to be University), Chennai- 603103, Tamil Nadu, India*
[c] *Department of Costume Design and Fashion, Hindusthan College of Arts and Science, Coimbatore-641028, Tamil Nadu, India*
*Corresponding author: anishs@hindustanuniv.ac.in (**M. Anish Sharmila)**

Abstract

Physical injuries are widespread in most populations, occurring through a life cycle. These physical cuts can lead to skin damage and wounds. Wound management poses a substantial socio-economic strain on contemporary society. In addition to numerous unintentional accidents, wounds may also be associated with diabetic foot ulcers, pressure ulcers, and other underlying medical conditions. A wound that does not fully heal and regain its normal structure and function after three months is classified as a chronic wound. The advancements in technology and the Incorporation of Smart technology have Inspired the creation of Smart Intelligent Bandages. These intelligent smart bandages have developed a vital innovation in the field of medical textiles that help in the continued monitoring and healing of Chronic wounds. This innovation is a smart way-finder in the field of medical textiles

Keywords: Physical Wounds, Smart Bandage, Chronic Wounds, Medical Textiles

1. Introduction

The most significant organ in the body, the skin is absolutely important not only in protecting the body from environmental pollutants and infections but also in avoiding heat stress and lack of water. A wound is a disruption of the skin tissue caused by physical damage resulting from regular activities, disease, prolonged exposure to high strain, traumatic events, or burns. Hypoperfusion and diabetes mellitus are two medical conditions that can change the way skin looks and feels, making it more open to physical damage [1].

Wound healing is an intricate, ever-changing, and sequential procedure that takes place following skin injury, resulting in the restoration of tissue. The skin typically undergoes regeneration following an injury, but this regenerative process can be impaired in certain situations, including diabetes mellitus, infections, and venous/arterial insufficiency, among others. Many types of wound bandages can help the body heal; however, selecting the right dressing necessitates a complete assessment of the wound, including its kind, size, depth, and color. New dressings have recently emerged, offering a fresh outlook on wound healing. However, there is currently no outstanding solution available to effectively treat acute and/or chronic wounds. Hence, it is imperative to conduct research studies on wound dressing to enhance wound healing [2]. Recent research suggests that approximately 2% of the global population experiences chronic wounds. The prevalence of serious injuries imposes a big cost pressure on medical facilities [3]. Incessant skin cuts are defined as ones that have disturbed healing processes, do not heal after a month, or are unable to recover fully and spontaneously (this includes diabetic foot ulcers and pressure traumas). A chronic wound's extracellular matrix (ECM) activity is weakened, the wound heals slowly or ineffectively, and the inflammation is prolonged and uncontrolled [1].

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Wound care directly influences the standard of living of patients and places a heavy the cost Economical load on medical treatment systems, making it an essential component [1]. Healing wounds are a complex and dynamic phenomenon involving the regeneration and growth of tissue, which occurs in four distinct phases [4]. These phases occur sequentially, with some overlap, in an interconnected cascade [5]. The specific lesion, the accompanying pathological characteristics, and the variety of dressing materials employed are the primary factors influencing the promotion of these phases. Currently, A diverse selection of wound dressing supplies is available to treat a variety of lesions due to technological advancements. However, the choice of a certain substance for a given wound is crucial to expedite the healing process [6]. Figure 1 illustrates the different phases of wound dressing evolution.

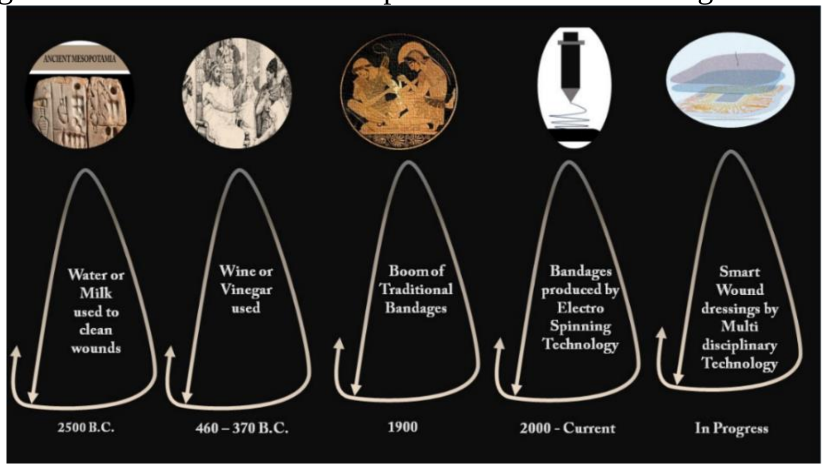

Figure 1: Different phases of wound dressing evolution [7]

The wound dressings must fulfill multiple functions (Figure 2).

1. It is necessary for it to be breathable to facilitate breathability.
2. It facilitates the elimination of exudates and necrotic tissue.
3. To serve as a protective barrier against external sources of infection.
4. To create a hygienic, humid, and cozy atmosphere.

Figure 2: Functions of Bandages [8]

The Wound Dressing is categorized into three distinct groups: a. Passive Bandages, b. Interactive Bandages, and c. Smart bandages. Passive materials, such as muslin gauze and tulle net use non-occlusive wound dressings to wrap wounds to facilitate restoration of their

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underlying function [6]. Gauze, a cost-effective bandage made of cotton, is commonly used to treat superficial Injuries without discharge from the wound. Nevertheless, gauze bandage tends to dehydrate the injuries and get stick to it for a while, resulting in complexities when attempting to remove and replace it. Moreover, gauze offers only a restricted level of defence to the lesion against bacterial infiltration. According to Han and Ceilley [9], the use of dry gauze can hinder the process of reepithelization and lessen the inflammatory response's efficacy by changing the levels of oxygen beneath the wound dressing. Furthermore, gauze can be infused with various chemicals to augment the therapeutic properties of the dressing. Contemporary gauze dressings are coated with moisturizing chemicals to regulate moisture levels at the wound site, resulting in quicker healing compared to using plain, dry gauze. According to Fonder et al.[10], using petrolatum in gauze facilitating the drying process at the wound site simplifies the reapplication of the dressing since it adheres less to the wound. Interactive dressings are types of dressings that can either partially or completely block the passage of air or water. They come in many forms such as films, foam, hydrogel, and hydrocolloids [6]. Foam or sponge dressings offer a substitute for gauze by effectively absorbing copious amounts of wound exudate, making them excellent for profound lacerations, ulcers caused by diabetes, minor burns, and ulcers resulting from venous insufficiency. When applied to a wound, polyurethane absorptive foam dressings create an aquaphilic link and protect the surrounding environment from water. This design allows for the passage of liquid and gas safeguarding the invasion of micro-organism. Furthermore, foam dressings along with other dressings like hydrogels, can speed up the reepithelization process at the wound site. Applying gentle pressure has been demonstrated to decrease over-granulation. The dressing's high absorbency ensures minimal adhesion and painless removal [11]. Therefore, they are not appropriate for wounds that are coated with eschar or are dry, as well as vascular ulcers, because they have a high level of absorbency [12]. Researchers are developing advanced smart bandages that have the potential to enable surgeons to remotely monitor wounds, reduce scarring, and accelerate healing using light or electricity (Anon n.d.-a). A thin layer of flexible electronics is embedded into smart bandages, allowing them to detect and analyze changes in oxygen, temperature, moisture levels, and pressure fluctuations at the location of the injury they cover (Anon n.d.-b). Figure 3 illustrates the distinct structural tiers of Passive, Active, and Smart Bandages.

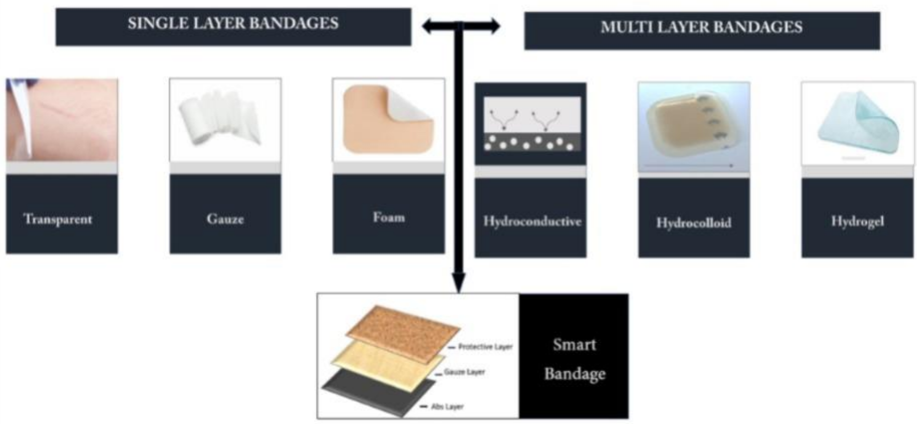

Figure 3: Schematic Representation of the Hierarchical Structure of the Smart Bandage.

Formerly, the products utilized were based on the "passive," additionally referred to as "plug and hide," approach, which encompassed tulle dressings, gauze, non-stick dressings, and lint. Passive wound dressings lack most of the characteristics of a perfect wound dressing and are having minimal utility as a primary wound dressing. Nevertheless, certain passive dressings can be beneficial as secondary dressings. There are several detrimental characteristics connected to the application of gauze.

- Because this is a fibrous fiber, it will contaminate the wound and is likely to shed very easily.
- Due to its great absorbency, it tends to dry the wound's surface quickly when used as a primary dressing.
- Moist gauze is conducive to bacterial growth due to its permeability to bacilli. This might boost the possibility of penetration and contamination of the wound.
- Additionally, it adheres to the wound and might potentially worsen the injury when removed, posing a risk of harm to the healing tissue and causing discomfort [13].

Intelligent wound wraps have developed a viable technique for enhancing the handling of wounds and care as a result of Progress in the field of medical research and development. Dressing for wounds has been employed for an extended period to facilitate the healing process. Wound dressing is essential for the restoration of the healing process to its normal state in chronic wounds that are unable to be recovered in a timely and organized manner [14]. Academicians have been motivated to develop novel strategies for improving the quality of biomaterials and fabrication technologies to create advanced wound dressings that produce superior healing results, as a result of the financial and psychological burdens associated with wounds [2]. Flexibility is a critical component of any smart dressing platform, as it enables the dressing to affirm the distinctive dimensions of the wound site [15]. The healing of critical incisions is expedited through the use of smart, technologically advanced bandages that facilitate ongoing monitoring.

The industry of bandages is well-established, while the industry of wearable electronics is only beginning to emerge. Presented in this assessment are the wound wraps as the foundation of wearable bioelectronics. The article commences as a comprehensive introduction regarding bandages and the advancement of smart sensors integrated into bandages. Subsequently, it proceeds to An orderly examination of the technical attributes of current bandages, a more pragmatic approach for future implementations, and the production procedures of wearable biosensors based on bandages. Despite advancements in flexible electronics and material science, wearable biosensors have only been partially available to the general public. The initial introduction of wearable electronic devices in the late 1970s brought them to the attention of the general public. The prime objective is to Streamline the functions of existing electrical gadgets; Yet, their development was expedited by technological advancements. In the present day, smart devices have undergone significant advancements on electronic gadgets that are designed to enhance and simplify daily activities, as well as to acquire continuous data on users' routine activities. These enable the immediate tracking of essential physiological indicators and provide monitoring, diagnostic, and performance assessment capabilities [8].

2. Detecting Wounds with Sensing Smart Bandages

Smart bandages with embedded sensors allow for wound diagnosis As well as live surveillance. Moisture, pH, temperature, and the presence of specific microorganisms are just a few of the characteristics that these bandages may measure. Medical staff can use this data to see how the wound is healing and decide whether more treatment is required. According to Hossain et al [1] smart bandages offer more accurate and objective wound information than traditional approaches that depend on subjective evaluations and visual inspections (Figure 4).

2.1.Biochemical sensor - A fluorescent nanomaterial known as carbon quantum dots (CQDs) has been developed by scientists to detect fluctuations in wound pH levels. In an additional design, phenol red was employed as an additional pH indicator in conjunction with CQDs to improve pH detection. The fluorescent signals and visible color can be detected by enabling remote, actual-time lesion status monitoring using on-site wound pH readings [16].

2.2.Body temperature sensing: Among the bodily heat-sensing devices are adaptable temperature sensors usually built from miniature metal resistive sensors. These sensors are frequently employed to observe the temperature of the epidermis in wounds. Hattori et al. [17] have utilized arrays of temperature sensors that were microfabricated to develop a conformal dressing that may be able to provide a wound area temperature distribution map.

2.3.Smart Bandages with pH Sensing: There have been reports indicating that the pH required to initiate the healing process varies depending on the type of lesion. To ensure that the pH values in the wound environment are continuously monitored, a variety of optical and electrochemical pH sensors have been derived [18]. A prospective form of smart wound dressing has been introduced through the unification of these sensors into bandages. Kassal et al. have developed Hydromel D4, a new wireless smart hydrogel-based wound bandage made of polyurethane that is pH-sensitive that is pH-sensitive. The bandage is composed of particles of cellulose covalently treated with a dye that indicates pH. Color change is detected by in the dressing's built-in photodiode, which thereafter digitizes the incoming data (ADC code) and wirelessly transmits it to the patient [19].

2.4.Flow monitoring of oxygen: Chronic wounds are characterized by a deficient supply of oxygen, which can impede the process of healing and thus result in injury of tissue [20]. Consequently, it is imperative to monitor tissue oxygenation to provide effective wound care. As part of one research, a typical electric component was utilized to create a wireless and flexible oxygen sensor smart bandage that may continuously track the wound's oxygen delivery [15]. Building the sensor included a flexible perylene C substrate and an electronic galvanic cell. The cathode of the electrochemical cell was silver, while the anode was zinc. In another study, a calorimetric oxygen sensor was developed to track oxygen saturation and maybe apply it to the surface of the lesion [16].

2.5.Research on moisture sensing: Wearable technologies are being developed to help wound care experts better assess the health of incisions. The Wound sensor is a working as a sensor that detects according to the moisture moisture content that is disposable and sterile. It is inserted into the dressing to monitor the levels of moisture in real time without damaging the dressing itself [21].

2.6.External pressure sensing: It is essential for the successful recovery of particular ulcers in diabetic feet, ulcers from pressure, and recurring sores. This involves the accurate observing the effects of pressure from the outside on the epidermis. Observing pressure on wound sites and skin is that it has the potential to be considerably enhanced by wearable pressure sensors. When external pressure is applied, piezo-resistive pressure sensors modify their electrical resistance, which results in the compression of the cavities or voids in their patterned composition. This process creates additional routes for electrons between electrodes [22]. For these sensors to be able to perform continuous monitoring, an external power supply is required [23] [24].

2.7.Inflammatory factors and diabetic ulcers are monitored: The healing process is delayed in diabetic wounds due to the protracted proinflammatory state, which is a result of the significantly prolonged compared to wounds that were not caused by diabetes throughout the inflammation phase of healing. As a consequence, this extended period can lead to the formation of chronic wounds [25].

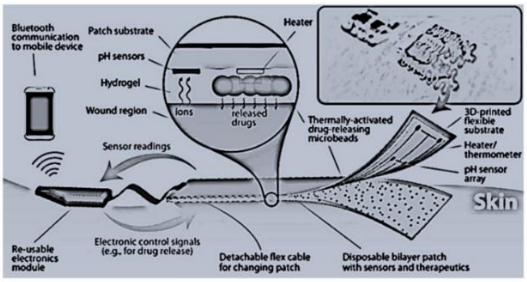

Figure 4: Schematic Representation of the Smart Bandages with Sensors [26]

3. Recent Innovations in Smart Bandages

Global healthcare systems worry about cutaneous wounds. Long and easy to recur, chronic wound recovery time burdens the patient's psychological and physical elements greatly. Rising demand for instantaneous observation and mending the patients' wellness away from a medical facility results from the expenses of per capita medical treatments rising and the need for medical services count of persons. Smart and Intelligent bandages are developed to track the wound's real-time status for this aim. Recent studies have taken place on smart bandages that led to the development of different new technologies in bandages. A few of them are discussed herewith.

By reducing the risk of disease infection, healthcare has a solution with this contactless multi-intelligent wearable device to track challenging regenerate wounds and provide ideal efficiencies for medical practitioners in the direction of embracing wearable sensors enabled by artificial intelligence using smart medical tools. Kalasin et al. [27] researched a wearable sensor called FLEX-AI. This sensor utilizes a Deep Artificial Neural Network (deep ANN) algorithm to monitor persistent wounds. The sensor operates through short-range communication and is integrated into a bandage that is equipped with MXENE and radio frequency tuning, creating a seamless and smart wound dressing. The deep artificial neural network (ANN) artificial intelligence model achieved a Ninety-five percent accuracy rate in recognizing the healing stage using a collection of pH-responsive voltage output under supervision obtained from contactless measurement. This accuracy was determined by analyzing the confusion matrix. The fundamental analytical structure of these intelligent bandages incorporates wound dressings made of poly (vinyl acrylic) gels using PANI/Cu2O nanoparticles, which generate a response to an electric current that changes pH to stimulate the healing process of wounds. Utilizing an adhesive acrylic inductance and a capacitive Mxene/PTFE electret, a chip-free bandage tag was effectively manufactured. This tag is designed to resonate at the frequency of the intelligent antenna that is worn by the individual. At an electrochemical potential of negative current, the healing dressing showed a slope of -76 mV/pH. Applying a greater activation voltage to the electrodes of the mixed PVA gel/PANI shell could allow cuprous ions to intercalate more effectively into the wound dressing. As a result, the two-terminal current response experienced a substantial exponential increase. The treatment of skin maladies with corticosteroids was categorized into fast-curing, slow-curing, and no-curing regimes in the healing phase diagram.

In conclusion, the technology of near-field detection provides sufficient data to inform treatment decisions and assess the efficacy of drugs in wound care. The difference between fixed dressings and irregular incisions is a significant yet overlooked issue in wound management, potentially leading to care outcomes that are inaccurate or incomplete. The ongoing progress in materials science, the Internet of Things (IoT), and Internet technology has led to increased demands for precision wound treatment. In this study, Kalasin et al. and He et al. [27] [28] have successfully implemented a wound recognition approach by extracting digital geometric information from specific irregular incisions by obtaining from particular irregular cuts digital geometric information. Coupled with offline smart material comes online wound image scanning and recognition production might significantly minimize partial wound closure or the risk of irritation to the surrounding normal tissue. The demonstration concept demonstrates that bandages with a dynamically changing pattern of Ag-modified gelatine possess efficient bactericidal qualities for useful applications. A mouse experiment conducted in living organisms demonstrates that wound-customized bands allow for a precise fit in irregular wound beds, leading to increasing the effectiveness of healing. The potential to transform individualized wound healthcare in many different clinical environments is present through the use of bandages that incorporate advanced technologies, including computer modeling, image recognition, and nanomaterial creation and modification.

For improved wound care and wound monitoring, new bandages based on bacterial cellulose (BC) membrane have been created by Liu et al. [29] as part of a new process for creating the upcoming line of intelligent bandages. By utilizing the vacuum filtering approach, Silver nanowires (AgNWs) are added to the BC membrane to produce a sandwich-structured material that is transparent, air permeable (389.98–547.79 g m−2 d−1), and exceedingly thin (about 7 µm). Bandages made of BC/AgNWs exhibit remarkable mechanical capabilities (108.45–202.35 MPa) and bactericidal properties against S. aureus and E. coli compatibility with living organisms, and conductivity (9.8 × 103–2.0 × 105 S m−1). The BC/AgNWs wound wrap is employed for the management of skin abnormalities involving the entire thickness in rats using electrical stimulation. This treatment involves the application of direct current at a strength of a rate of six hundred microamperes for 1 hour, occurring on alternate days. The bandage efficiently facilitates the recovery of wounds by promoting the secretion of vascular endothelial development factor (VEGF). The use of BC Bandage is to monitor ailments and attain an elevated state of accuracy of 95 percent in classifying several wound healing is a process that involves several stages, including bleeding, inflammation, cell proliferation, and remodelling using a convolutional neural network. Wound infection is a critical healthcare problem that can result in intense pain, sepsis, and potentially the need for amputation. Shi et al. [30] have created a wearable smart bandage, battery-free, and wireless to tackle the difficulties of point-of-care wound diagnosis. The bandage is intended to identify factors of bacterial pathogenicity. Using electrochemical differential pulse voltammetry, the biomarkers—sortase A and pyocyanin, were linked to two main kinds of infection caused by bacteria—Gram (positive) Both Gram-negative bacteria and Staphylococcus aureus Some Pseudomonas aeruginosa were discovered. The Ti3C2Tx MXene material has been utilized as a coating on the electrode to augment its Perceptiveness. Pyocyanin can transmit electrons to sense to another electrode because of its redox properties, on the other hand, a peptide conjugated with the electroactive ferrocene compound was meant to especially identify sortase A. The smartphone was able to wirelessly obtain energy and transmit data thanks to a near-field communication module.

Featuring extensive detecting capabilities of 1 picogram per milliliter to 100 nanograms per milliliter for sortase A and 1 micrometer to 100 micrometers for pyocyanin, the integrated system displayed outstanding linearity and great sensitivity. Furthermore, the animal experiments showed how well The intelligent bandage demonstrated the ability to conduct multi-biomarker screening of wounds wearable tech is an easy, non-intrusive way to the effective platform for identifying bacterial virulence factors in the immediate environment. Wu et al [31] have made a new electrical bandage contact lens that is driven by wireless energy that has significant potential for managing infected wounds (EBCL) to create a focussed external electric field to hasten the healing of corneal lesions and aid with eyesight restoration. The floral-shaped layout design used A stimulating electrical system that works without wires and can be easily and undetectably integrated into a bandage contact lens without impairing vision. An analysis of the consequences of an external voltage field on the enhancement of healing of corneal wounds is carried out in the lab. The purpose of the investigation is to see how the electric field affects the directed movement and positioning of corneal cells. According to RNA sequencing research, electric stimulation may be involved in regulating the movement, multiplication, and division of cells. Moreover, the electrical stimulation of corneal wounds in rabbits' eyes has been demonstrated to speed up their entire healing using the wireless EBCL, while the control group has a delay in recovery and obvious corneal abnormalities. An innovative and cutting-edge kind is the wireless, patient-friendly EBCL of intelligent gadget that holds great potential as a therapeutic approach for ocular ailments.

Zhang [32] has showcased A framework for analogous computing by employing paired ONN for data in real-time gathering, system analysis, and processing that are well-suited for smart bandage applications. Upon detecting the data anomalous, the ONN promptly subjects the data discussed to its processing unit for initial processing. Conventional digital processing necessitates the delivery of all atypical data. On the other hand, to transmit only the data showing a lack of synchronizing, the analogue processing unit merely Needs to identify the period and frequency at which convergence occurs and compare them with the storage mode of healthy skin. ONN enhances processing efficiency when used in portable devices. By simulating both Simulink and Cadence, the alignment between the mathematical models and hardware circuits in the construction of this hardware has been successfully done. This substantiates The viability of integrating the circuit into the smart bandage application. An AM model with two layers of hierarchy is proposed. This is because to find the nearest neighbour, the detected pattern always needs to be compared using all kinds of storage strategies. Relative to a single AM model, the clustering structure consisting of two layers significantly minimizes the number of patterns These must be kept across numerous stages of execution. Kaur and Purwar [33] provide a comprehensive explanation of various nanomaterials used in situ biosensors real-time for wound state monitoring. These biosensors are designed to detect and measure pH levels, odor, temperature, motion, pressure, visual changes, moisture level, uric acid levels, blood glucose levels and oxygenation regarding smart stimuli-responsive and also detailed information pertaining to clever stimuli-responsive drug release devices that are created for electronics inspired by the skin.

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Smart powder bandage developed by Polaka et al. [34] is created using freeze-drying and has a water content of less than 1% when stored. When it comes into touch with the fluid that comes out of a wound, it creates layers of a gel-like substance, which improves the way peptides are delivered. This approach is specifically designed for peptides that are sensitive to temperature, such as EGF. It overcomes the drawbacks of traditional hydrogels and provides a solid basis for the efficient administration of therapies in applications related to injury healing applications. It is crucial to create wound dressings that have several functions, including the ability to kill bacteria, reduce inflammation, stop bleeding, and promote healing, to enhance healing action. This SPB is designed to enhance the healing of wounds by utilizing a combination of silver nanomix (Silnanom) and bioactive epidermal growth factors (EGF) as therapeutic agents. Based on preliminary results of the smart powder bandage (SPB) research, it was determined that the Silnanom particles were distributed uniformly across the interconnected network of polysaccharides. The versatile intelligent bandage demonstrated significant characteristics that inhibit the growth of bacteria such as Staphylococcus aureus and Escherichia coli. Additionally, thorough investigations on The biocompatibility of the substance has been demonstrated through tests of hemocompatibility, cell compatibility, and in vivo investigation. In addition, the In a mouse wound model with full-thickness wounds, multifunctional EGF@Silnanom SPB was able to effectively reduce pro-inflammatory markers, promote collagen synthesis, stimulate blood vessel expansion, and speed up the healing process. This was accomplished by constantly releasing Silnanom and EGF. Silnanom and EGF. Furthermore, the hemostasis research conducted on the mouse model with tail amputation verified that the hemostasis had been achieved the capabilities of the EGF@Silnanom SPB. In summary, the EGF@Silnanom SPB, which serves several functions, exhibits considerable potential for healing skin wounds. It provides a powerful and efficient remedy for the difficulties associated with traditional wound dressings. Because of the synergistic effect that LGG and MXene have on one another, Shariffuzaman et al. [35] were able to build a hybrid scaffold consisting of LGG and MXene that exhibited excellent conductivity and improved electrochemistry while also having a high heterogeneous electron transfer (HET) 2D MXene nanosheets were applied at a rate to functionalize 3D LGG sheets by the use of a C–O–Ti covalent crosslink. In the study, to make a wound dressing, the hybrid scaffold was placed onto PDMS that is intelligent, flexible, and capable of stretching has been applied. This bandage is equipped with sensors that can at the site of the wound, one should take measurements of uric acid (UA), pH, and temperature. The UA sensor, which was integrated, demonstrated a quick reaction to UA throughout a broad range of 50–1200 µM. It exhibited a remarkable sensitivity of 422.5 µA mM^{-1} cm^{-2}, while simultaneously exhibiting an exceptionally low detection limit of 50 µM. The pH sensor also had a linear Nernstian response with a high sensitivity of -57.03 mV pH^{-1} in the pH range of 4-9, relevant to wound conditions. The R^2 for this response was 0.998. The temperature sensor showed a fast and consistent linear response to temperature changes between 25-50 °C, with a sensitivity of 0.09% $^{o}C^{-1}$ and a correlation coefficient of 0.999. This adaptive intelligent bandage has the potential to revolutionize wound management and therapy outcomes. Mostafalu et al. [15] developed a flexible smart bandage with wireless data transfer, small readout circuitry, and incorporated flexible oxygen sensors. Flexible oxygen sensors were manufactured and demonstrated to possess sufficient sensitivity and a linear output. A tiny packaging was used to configure commercial components, resulting in the achievement of combined digital readout and wireless telemetry. The bandage was fabricated using a 3D printing technique, utilizing an elastomeric material known for its exceptional strength and flexibility. This material was chosen specifically to provide a durable and resilient wound dressing. By affixing the wireless readout system onto the smart wearable bandage, a digital platform is created that allows for

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the continuous monitoring of Oxygen concentrations in the infected areas. These messages are transmitted immediately to a computer. It is straightforward to incorporate various sensors and readouts add off-the-shelf components to the front-end amplifier. Nevertheless, the circuit board has the potential to be substituted with a flexible PCB, which would enhance the practicality of intricate designs.

4. Challenges Associated with Wearable Bandages

The utilization of preexisting products to develop a completely self-governing gadget that serves as a handheld medical care expert will significantly affect people. However, several obstacles currently hinder the widespread adoption of suitable and skin-like tools for worldwide medical systems. These include an absence of a consistent standard for validating wearables, the need for end-user acceptance of the product, and the requirement for cost-effective production in large quantities technique with a positive cost-to-benefit ratio.Upon examining the extensive five-thousand-year history of bandage development and wound management, it becomes evident that there are notable parallels to wearables. These commonalities could potentially provide viable solutions for the aforementioned issues. Currently, the validation procedure for most foams, composite, films, and hydrogel bandages is complex and time-consuming. However, these products provide valuable qualities that can be utilized in the development of wearable biosensors [8]. Materials have advanced; Flexible electronics, sensors that mimic human skin, and wearable electronic devices that fit to the body have evolved and have garnered considerable interest. However, these technologies are still not widely employed in practical applications due to issues related to usability, reliability, and durability. Researchers are currently investigating the application of flexible and soft components like textiles and polymers for various applications. Bandages, in particular, have garnered interest Their capacity for close touch and skin adhesiveness. Research still needs complete application of knowledge on the use the integration of sensors into the skin of humans, the utilization of widespread production techniques, and the incorporation of these technologies into the mainstream consumer market. However, significant efforts are made in areas where acute and chronic wound therapies, with substantial research, development, and financial resources being allocated. This is due to the significant and growing influence that these treatments have on healthcare systems globally [8]. Creating a unified structure for smart healing equipment using wearable systems and gadgets to enhance comfort, health, and well-being is undeniably a crucial approach to support and enhance research and development. Academic research must address concerns related to the efficiency and dependability of systems. Wearable systems and gadgets require software and hardware that are efficient and unobtrusive. The smart bandage industry will experience significant growth shortly by successfully addressing and overcoming these issues.

5. Future Direction of Smart Intelligent Bandages

The integration of intelligent technology has caused the creation of innovative wound treatment and rehabilitation solutions, such as Intelligent smart wound wraps with multifarious functions which can concurrently observe and cure injuries. Due to the availability of a variety of biocompatible and cost-effective wearable sensors that can monitor the healing process in real-time, as well as the advancement of dynamic dressings that actively Address the current state of the wound and discuss the future of wound care management is considered optimistic. Smart bandages can substantially diminish the likelihood of infections of wounds thus expediting the process of healing wounds. Administering medications or chemicals for treatments directly to the infected site, can expedite the process of healing and minimize blemish. It is anticipated that the ongoing use of wound surveillance and therapy systems will greatly enhance patient happiness, improve patients' quality of life, and reduce the strain on healthcare systems [1]. Intelligent clothing, sometimes referred to as e-textiles, can include a range of novel sensing devices and their electrical functionality through different fabrication methods. Electronic clothing will eventually become increasingly self-sufficient to enable the purpose of portable wearable sensing bandages for remote patient care and self-health management. Furthermore, smart e-bandages can contribute to innovations in cloud computing and big data. In addition to being utilized for fitness tracking and healthcare, wearable smart bandages also help to improve augmented reality and the Internet of Things (IoT) are the subjects of discussion technologies. In the coming decade, it is anticipated that textile-based technology will merge with IoT, artificial intelligence, human-machine interfaces, and cloud technologies. It is anticipated that AR will revolutionize our daily existence in the Internet of Things. This is because smart textiles, which encompass intelligent and computing garments, have a great spectrum of possible uses. Figure 5 is a schematic representation of the future directions of smart bandages The Internet of Textiles is a continuation or expansion of the Internet of Things (IoT) [36].

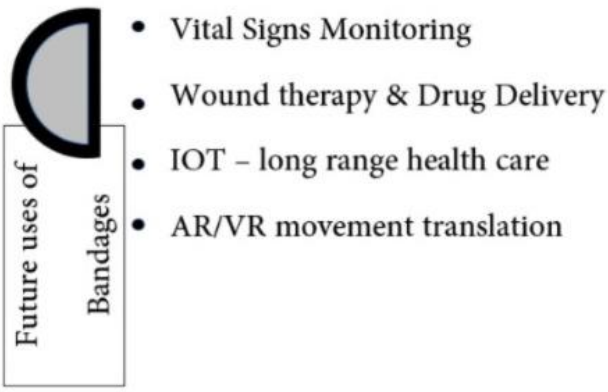

Figure 5 Future Direction of Smart Bandages [8]

6. Conclusion

Because the smart bandage system is inexpensive, does not require batteries, is adaptable and has the potential to be readily installed on the anatomy of humans, it demonstrates a significant deal of potential to treat infections that are chronic in the context of wound care. The study speaks to the significance of intelligent lesion wrap as a developing plan for the management of lesion care. Additionally, the highlights of the study are to differentiate various forms of intelligent smart dressings designed to enhance the process of healing wounds. To make it more practicable to use, additional study needs to be conducted, and an awareness campaign needs to be organized among the general population.

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