We are IntechOpen, the world’s leading publisher of Open Access books
Built by scientists, for scientists

6,600
Open access books available

177,000
International authors and editors

195M
Downloads

154
Countries delivered to

TOP 1%
Our authors are among the most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™
Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com
Chapter

Minimally Invasive Microneedle: A Novel Approach for Drug Delivery System and Infected Wound Care Management

Bidhan Pramanick and Aishwarya G. Patil

Abstract

Chronic wound healing has become an area of fundamental research. Wound healing for a diabetic patient is one of the significant challenges in the biomedical field. Diabetes is a globally challenging disease that has affected around 400 million people. Many therapeutic factors are introduced to treat chronic wounds, with minimal success due to difficulty in delivery of the drug to the wound location. Microneedle patches are considered an efficient medical treatment procedure to address wound healing problems. The wound healing is accelerated, and the bacterial infection is inhibited by the devices based on microneedle with the loaded active drugs (including hemostatic drugs, bacterial drugs, and anti-inflammatory drugs). The wound healing process is generally divided into three steps: inflammation, proliferation, and tissue remodeling. This chapter will discuss the significant challenges and the advantages of microneedle applications in chronic wound healing.

Keywords: wounds, wound healing, microneedle, drug delivery, disease diagnostic

1. Introduction

A wound can be defined as a disruption of the functioning and anatomical structure of the tissues. This disruption ranges from more severe damage to the subcutaneous tissue with tendons, vessels, nerves, parenchymal organs, muscles, and bones being affected or a small break in the epithelial tissue [1].

Wound healing is a process of recovery, and it has three phases: inflammation, proliferation, and maturation. However, if the process is not thoroughly studied, this is not enough to understand wound healing. Wound healing involves complicated continuous interactions between cells and mediators. Recently, there has been an increase in the understanding of cellular interactions and inflammatory mediators, as new mediators are discovered every year [1, 2].

The complicated and organized cascade of biochemical and cellular events is triggered by an injury resulting in a wound. The nonclosure of the wound or delay in healing is the result of prolongation or failure in any one of the phases of wound
healing. This delay is one of the significant clinical issues affecting health care expenditure. A better understanding of the pathophysiologic process can better grasp the fundamentals of wound healing physiology [3]. The macroscopic appearance of an open wound is shown in Figure 1.

The damaged tissue is restored after the tissue lesion occurs, followed by the tissue repair and regeneration process involving a series of cellular and molecular events. The amalgamation of different dynamic processes involving blood cells, parenchymal cells, and soluble mediators gives rise to different wound healing phases. The tissue edema is developed due to soluble mediators. The area of the tissue injury is reduced by contracting the myofibroblasts and fibroplasia in the proliferative stage. Re-epithelialization and angiogenesis are still observed at this stage. The mesenchymal components are generated by the endothelial cells, which are adequately orchestrated by the signaling proteins. This process is called as Hedgehog pathway [4].

This chapter focuses on the applications of microneedles for wound care management. However, it is also imperative to understand the types of wounds, different stages of the healing process, and available treatments before discussing microneedle-based treatments. Details on wounds and their treatments are presented in the next sections, followed by microneedle application for wound healing [5].

2. Classifications of wounds

Wounds are classified based on many criteria. An essential factor in managing the injury and the wound repair is the time elapsed since the injury. Thus, depending upon the time frame of healing, wounds are clinically categorized as acute or chronic [6].

2.1 Acute wounds

The self-repairing wounds that proceed with an orderly healing process, with an anatomical and functional restoration as the end result, are called acute wounds. A total of 5–10 days or a maximum of 30 days is the duration of time needed for acute wounds to heal. The surgical procedure or traumatic loss of tissue gives rise to acute
wounds. Traumatic wounds usually involve bone fractures or only soft tissue [6]. An image of the acute wound can be a small cut on the finger, as shown in Figure 2.

2.2 Chronic wounds

The wounds that are not repaired in a timely or orderly manner and fail to follow the typical healing stages are called chronic wounds. Many factors cause the disturbance in the healing process of the four stages of the wound, such as tissue hypoxia, necrosis, exudate, infection, and excessive levels of inflammatory cytokines. A nonhealing state is perpetuated due to the cascading of tissue responses to the continuous state of inflammation in the wound. Chronic wounds relapse frequently, and the functional and anatomical outcomes are inferior. Pressure, burns, vasculitis, naturopathic, arterial, and venous insufficiency are causes of chronic wounds [6]. An example of a chronic wound is shown in Figure 3.
2.3 Complicated wounds

The combination of tissue defects and infections is classified as a complicated wound. It is a unique entity. Complicated wounds are affected by different types of infections. A wide tissue resection and traumatic or postinfectious etiology are a few of the causes of complicated wounds. Irrespective of the size, management, cause, and location, every wound is contaminated. The infection that develops depends on the number and type of microorganisms, virulence, the patient’s inherent resistance, and the local blood supply. Heat, redness, pain, edema, and limited or loss of function of the affected part are the symptoms or the typical characteristics of infection. The wound classification is also done based on the criteria, such as degree of contamination, morphological characteristics, etiology, and communication with solid or hollow organs [6]. Wounds are also classified as open and closed. In the case of open wounds, the underlying tissue is exposed, and the skin layer is damaged. In the case of a closed wound, the skin is not severed, but the underlying tissue is damaged [7]. The image shown in Figure 4 depicts a complicated, open, and contaminated wound.

3. Wound healing process

The wound healing process mainly consists of four stages: Hemostasis, inflammatory, proliferative, and remodeling [8]. The graphical representation of this sequence is shown in Figure 5.

- **Hemostasis**: In this phase, blood clotting causes the wound to close. The moment blood outflows the body (due cut or some other reason), this phase starts and restricts the blood flow by constricting the blood vessels. When the blood vessel’s epithelial wall ruptures, the aggregation and adherence of platelets to the subendothelium surface take place within seconds. Within sixty seconds after the above event, the adherence of the first fibrin strand takes place. The blood gets converted from liquid to gel by releasing prothrombin and procoagulants when the fibrin mesh begins. The wound area contains the trapped blood cells and platelets due to the formation of thrombus or clot. Thrombus is vital in wound healing, but if it gets detached from the vessel wall and travels through the
circulatory system, it might cause strokes or pulmonary embolism [9]. The process of hemostasis is shown in Figure 6.

• Inflammation: It begins immediately after the injury, which causes localized swelling due to leakage of a transudate. Infection and bleeding are prevented by inflammation. The bacteria, damaged cells, and pathogens are removed from the wound area in this phase. The common symptoms observed in this phase are heat, pain, redness, and swelling, which are caused due to growth factors, nutrients, enzymes, and white blood cells. This phase is a problem if it is excessive or prolonged, even if it is a part of the natural process of wound healing [10]. Figure 7 depicts the inflammatory phase.

• Proliferation: The new tissue made up of extracellular matrix and collagen is rebuilt in the wound. With the new tissues being developed, the wound starts contracting. To ensure the granulation tissue is healthy so that it receives enough nutrients and oxygen, the construction of new blood vessels must take place. The contraction of the wound takes place by the myofibroblasts, which grip the wound at its edges, similar to the smooth muscle cells. If the granulation tissue is healthy, it does not bleed easily. The granulation tissue is red or pink in the healthy stages of healing of the wound, and also the texture is uneven. Poor perfusion, ischemia, and infection are caused due to dark granulation tissue. Epithelial cells finally reappear in the injury. Keeping the wound hydrated and moist enhances the process of epithelialization. In order to maintain optimum humidity and improve epithelialization, semiocclusive and occlusive dressings are applied within 48 hours of the injury [11] Figure 8 shows the graphical representation of all the stages of wound healing.

• Maturation or remodeling: The complete closure of the wound takes place. Remodeling of collagen from type 3 to type 1 occurs. Apoptosis is also called programmed cell death, in which the cells that are no longer needed but were
used for repairing the wound are removed [12]. Disorganization of the collagen, which was laid down during the proliferative phase, takes place; the wound becomes thicker. The tensile strength of the healing tissue is increased by remodeling the collagen into a more organized structure along the lines of stress. Matrix metalloproteinases are secreted by fibroblasts. Type III collagen is remodeled into type I collagen by enzymes. After around 21 days of the injury has taken place, the remodeling begins and may continue for a year or more. The wound areas, which are healed, are weaker than the uninjured skin, even with cross-linking. They have only 80% of the tensile strength of healthy skin [13]. Figure 9 is the diagrammatic representation of the remodeling phase.

4. Chronic wound

Chronic wounds do not follow the timely fashion of wound healing. Burns are included in chronic wounds as they take a long duration to heal than acute wounds. A large variety of surgically induced wounds and traumatic wounds are considered as chronic wounds by surgeons, as they heal unexpectedly slow. These chronic wounds

![Diagram of Hemostasis](image-url)
are also considered as vascularly compromised or infected. Chronic wounds also include the entire category of skin ulcers [14].

Despite good wound management, chronic wounds remain intractable, and they fail to follow the orderly phases of healing. Chronic wounds are detained in a self-perpetuating inflammatory stage. There are a high number of factors that delay wound healing, such as vascular insufficiency, chronic disease, malnutrition, diabetes, and aging. It is also affected by local factors, such as infection, edema, and pressure [15]. The wound gets locked in a prolonged and heightened inflammatory state due to the subsequent tissue damage, which is characterized by reactive oxygen species (ROS) and destructive enzymes perpetuating the cycle associated with neutrophil infiltration. If the primary noxious factor is eliminated, many chronic wounds can be effectively healed [16].

Figure 7.
A picture of the inflammatory phase indicating the inflammation and the action of fibrin and phagocyte [10].

Figure 8.
Graphical representation of four stages of wound healing and their mutual relation is depicted in the figure above [11].
Patients with chronic wounds suffer the loss of function, financial costs, pain, and infections due to nonhealing ulcers, leading to sepsis or amputations. Diabetes, obesity, and the aging population are some of the high-profile issues that give rise to chronic wounds. In most parts of the world, these health issues are on the rise, and with this, the occurrence of diabetic, venous, and nonhealing pressure ulcers also increases. Unfortunately, the appropriate care and education about chronic wounds are lacking. The causes of chronic wounds overshadow their significance, and also, their costs are poorly documented. However, the quality of life of around 40 million people is impacted adversely and persists as a silent epidemic [17].

There are three main categories of chronic wounds: diabetic ulcers, pressure ulcers, and venous ulcers. There exists a fourth small group secondary to arterial ischemia [14].

4.1 Venous ulcers

Venous stasis ulcers affect around 1–2% of the adult population, primarily women and the elderly. They occur mainly in the lower limb and account for more than half. Venous hypertension and congestion are mainly responsible for venous ulcers caused due to venous thrombosis or valvular incompetence [18]. The blood vessel permeability is increased due to back pressure, which leads to leakage of red blood cells and macromolecules into the perivascular space. These then act as chemoattractants for leukocyte infiltration. Inflammatory processes associated with reperfusion exacerbate the injury, and leg elevation restores the effective loss of circulation. Venous ulcers
commonly occur in the medial malleolus. They tend to be shallower and more prominent and are irregular with ill-defined margins [19]. Figure 10 depicts the various stages involved in the formation of venous ulcers.

4.2 Arterial ulcers

Arterial ulcers are rare when compared to venous ones. The consequence of arterial insufficiency, which is caused by atherosclerosis or rarely thromboembolic or radiation damage, gives rise to arterial ulcers. When the arterial lumen narrows down, it reduces perfusion, which leads to ischemia and hypoxia [18]. Peripheral vascular disease is defined as the blockage of arteries other than those supplying blood to the heart and brain. An increase in age, hypertension, diabetes, smoking, and hypercholesterolemia are the significant risk factors for these ulcers. The management of risk factors and reconstructive surgery or angioplasty to restore the peripheral flow is a part of wound therapy. These ulcers usually occur distally over bony prominences and are present with a round and the sharply demarcated border [20]. Figure 11 is an image representing an arterial ulcer.

Figure 10.
Various stages of venous ulcers: from skin redness, inflammation of the subcutaneous tissue in the area of the lower leg progresses to formation of wound on the surface [19].

Figure 11.
An image representing an arterial ulcer [5].
4.3 Pressure ulcers

These kinds of ulcers are common in patients who have compromised sensory perception and mobility, are either paralyzed or unconscious, and cannot respond to the periodic need for repositioning. When the capillary pressure is exceeded by tissue compression due to prolonged, unrelieved pressure or shear leads to ischemia necrosis. This is the result of tissue hypoxia and ischemia-reperfusion injury. Usually, skin over bony prominences, such as the sacrum, hips, and malleoli, is vulnerable to pressure ulcers. This may be caused after as little as two hours of immobility [18]. Figure 12 shows the four different stages of pressure ulcers.

4.4 Diabetic ulcers

Around 382 million people worldwide suffer from diabetes mellitus, which is one of the leading causes of death. Diabetic foot ulcers are a common serious complication of diabetes and are very common. Diabetes associated with peripheral neuropathy increases the risk of ulceration due to repeated mechanical stress, which creates a weakened, insensate foot, heightened by disrupted perfusion. Wound healing is directly disrupted by metabolic derangements caused due to hyperglycemia in diabetic patients [18]. There is a higher risk of re-ulceration, amputation, and death in patients suffering from diabetic foot ulcers. This has drawn greater attention to diabetic wound healing and limb salvage in the recent past [21]. Figure 13 shows patients suffering from diabetic ulcers.

5. Treatments for faster wound healing

Techniques like cushions, magnetic fields, pressure-relieving beds, ultrasound, and electric fields are also used along with conventional medications. The healing and prevention of pressure wounds are addressed by the aforementioned methods [22].

Figure 12. Schematic representation of four different stages of pressure ulcer and penetration of wound at different stages [18].
5.1 Wound healing using laser therapy

LASER (light amplification by stimulated emission of radiation) therapy is one of the potential methods. The efficiency of LASER therapy is affected by different parameters. There has been a variety of studies to develop this technique for various medical applications [23]. Figure 14 shows the wound healing procedure using laser therapy.
Recently, lasers have enhanced the nonsurgical method of the wound healing procedure. A therapy of low-power light is a great approach to treat lesions of wounds using light devices like LASER (light amplification by stimulated emission of adiation). A laser is used to repair the biological injury. However, it is not entirely understood the role of laser in reducing pain and repairing tissue. The parameters like optical properties of the tissue, wavelength, and dosage of light affect the interaction of biological tissues and light. Laser has features like various active media types, including solid, liquid, and gaseous materials and also resonant optical cavity [24]. A wide range of therapeutic effects is produced with an account of different irradiation conditions, such as frequency, duration of treatment, and exposure time, and also other laser parameters, such as energy, pulse frequency, pulse duration, power, and wavelength. The wounded cells are affected with suboptimal growth with laser therapy without affecting normal cells [10].

When the dosage of laser therapy was more than 5 J/cm², it revealed more considerable biological effects. It is also shown that at lower doses, no biological effects were
observed, and at very high doses, the cell function is inhibited. Hence an optimum dosage of laser gives better results in wound healing [18].

5.2 Ultrasound therapy for wound healing

Ultrasound (US) waves have always proven promising therapeutic outcomes for various wounds. The main advantages of US in healing the wound are as follows: highly steering, focusable and high penetration into the wound bed. The physiological mechanisms of US in wound healing are based on its antimicrobial effects. There is no definite dose response observed in the clinical trials of this technique, despite evidence of therapeutic efficiency for chronic wounds in particular. To better understand the dose response and mechanism of action of US methods, more clinical trials and in vitro trials are required. Figure 15 shows the device used for ultrasound therapy [25].

The low US frequencies in the range of 20–120 kHz are used in wound healing applications. The process of producing heat in the tissue by delivering nonionizing radiation in the form of mechanical sound waves is called the therapeutic US, which is a physical method. When the frequencies 1.0 MHz and 3.0 MHz are used to exert the therapeutic US, it attains a depth of 5 cm and even more beneath the body surface. It is also the often used deep-heating modality.

Figure 15. A photograph of a device used for ultrasound therapy [25].
Very high frequencies of US may cause cell death, whereas low frequencies of US have beneficial effects on the wound [26]. The wound healing procedures, such as gene treatment, fracture repair, sonoporation, sonophoresis, and physiotherapy, use low power of US. By altering the wave intensity and wavelength, the US dosage could be changed. US therapy can either be pulsed or continuous. More heating effects are exerted by continuous US therapy. The pulsed US has on and off cycles; this variation changes the dosage of US therapy [27].

6. Wound healing treatment using microneedle

A different level of success has been achieved using various technologies to treat chronic wounds. Additional treatments like the application of fillers such as collagen sponges, usage of negative wound pressure, hyperbaric oxygen therapy, application of select growth factors, advanced wound dressings, systemic or local antibiotic therapy, and, more recently, the use of cell-based tissue-engineered products have been applied depending on the type and severity of the wound that is being treated [28]. In this section, we have mainly focused on the details of the microneedle, followed by the wound treatment using microneedles.

This technique is based on the use of tiny needles, so small that they are measured in micrometers (millions of a meter/μm). These microneedles are designed to deliver medicines. In terms of how they work, microneedles are similar to that transdermal patch, for example, the ones used for nicotine delivery that helps people give up smoking compared to the traditional hypodermic needles [17].

The epidermis plays an essential role in acting like a protective layer and keeping things out and protecting all the penetrants. It forms the 10–50 μm layer. When we talk about drug delivery, we mainly aim to get the medicine across this layer. It is this issue from where the concept of the microneedle was developed [29].

Microneedles were made worldwide using the materials like silicon, glass, and metal by the researchers during late 1990s. Microneedles are capable of creating an easier passage to reach the bloodstream in the lower dermal layers. This is a pain-free and easy way of delivering a wide range of medicines across the skin. Figure 16 is an image of an array of microneedles. Figure 17 shows the penetration of a conventional needle and a microneedle [30]. The dimensions of the microneedle are as shown in Figure 18.
Figure 17. Diagrammatic representation of three DDS delivering drugs through various layers of skin: Topical DDS, microneedles-based DDS, and hypodermic needle [31].

Figure 18. A schematic representation of a microneedle and various sections of a microneedle array [31].

Minimally Invasive Microneedle: A Novel Approach for Drug Delivery System and Infected... DOI: http://dx.doi.org/10.5772/intechopen.105771
7. Types of microneedles

7.1 Solid microneedle

Solid microneedles are arranged as an array in a two-part system; microscopic wells are created on the skin using this microneedle just deep enough to penetrate the outermost layer of the skin, and then a transdermal patch is used to apply the drug. Collagen induction therapy is a method in dermatology, which uses solid microneedles. This method involves the repeated puncturing of the skin with microneedles, wherein the expression and deposition of elastin and collagen proteins are induced [32].

7.2 Hollow microneedle

These are similar to solid microneedles with respect to the material. They act like a reservoir containing the drug to be delivered to the site directly. The flow rate of the microneedle influences the drug delivery; therefore, a flawed design or excessive swelling may cause clogging of the array. Hollow microneedles have a higher probability of collapsing under pressure, thus failing to deliver drugs [32].

7.3 Coated microneedle

Coated microneedles are designed using metals or polymers, similar to that of solid microneedles. Here the drug is directly applied to the microneedle, unlike in other cases where patches or applicators are used. To ensure the proper delivery of the drug, thickening agents or surfactants are used to cover coated microneedles. The chemicals that are used on coated microneedles are known as irritants. There is sometimes the risk of local inflammation in the area where the array was used. In such cases, the array can be removed immediately without harming the patient [32].

7.4 Dissolvable microneedle

In the case of dissolvable microneedles, they encapsulate the drug using a nontoxic polymer, which is dissolved completely when it enters the skin. Fibroin is a polymer that is derived from silk protein. This fibroin can be molded into structures of microneedles and also dissolves once into the body; therefore, in the recent past, researchers and pharmaceutical companies have started to study its mechanisms and potential [32].

7.5 Hydrogel-forming microneedles

This type of microneedles has no drug in itself. They follow the technique of swelling in the skin to allow the diffusion of the drug inside the reservoir layer attached to the microneedle for dermal microcirculation for systemic absorption [32].

The various types of microneedles explained above are shown in Figure 19.
8. Applications of microneedles

The applications of microneedles in different domains are shown below in the chart in Figure 20 [33].

9. Recent work in chronic wound healing using microneedles

In the case of chronic wounds, the delivery of topically administered therapeutics is disrupted due to the discharge of exudate, the presence of eschar, and a harsh
chemical microenvironment rich in various enzymes. Therefore, to make therapeutics more available at the wound bed and also control the distribution of the drug spatially, by having control over the drug content of individual needles, MNA systems are developed. Based on the control temporal release profile, MNAs are classified as passive, active, and smart releases [34]. Researchers have utilized these different strategies to deliver different therapeutics to enhance the healing of the wound process and solve the crucial dysfunctions existing in the chronic wound microenvironments [35].

9.1 Passively delivered biological materials

This method is one of the simplest available methods to carry biologics from MNAs, despite the fact that alteration of release kinetics is not possible when the passive release MNA is in action. However, they can be altered during the development phase of MNAs by changing various components of the system design. Several chronic wound symptoms, such as low vascularization and infection, are addressed using this technique [36]. Fabrication of MNA using an antibiotic agent encapsulated within an MNA structure or an antibacterial material is the straightforward approach to creating antibacterial MNA. Both the concepts mentioned above were achieved by Yi et al. by filling zinc nitrate (Zn^{2+}) into chitosan (CS) MNs, which defeated unloaded CS MNs in the eradication of *S. aureus* and *E. coli*. The worth of piercing the biofilm to eliminate infection was highlighted when the MNAs were capable enough to kill a large number of bacteria compared to a topically applied film with the same
The different parts of the hybrid microneedle including the scaffolding material used for preserving the stem-cell functionality offered by the core-shell structure for facile insertion are shown in Figure 21A. Figure 21B shows the mechanism involved in MNA-based delivery of stem cell action meant for enhanced regeneration [38].

9.2 Active system

MNAs that work on passive delivery of biological materials provide effortless and smoothly applicable point of care (POC) systems. It does not adhere to the needs connected with the wound environment, which is dynamic in nature throughout the process of healing. The effect of therapeutics is different at different stages of wound healing. Therapeutics that may improve healing at one stage of healing can prove to be harmful or useless at a different stage. The application of active MNA systems could be a promising alternative to passive MNAs. In this mechanism, the dissolving Gantrez® AN-139 MNA was loaded with photosensitizing methylene blue to perform photodynamic antimicrobial chemotherapy (PACT). In this approach, the photosensitizing drug is activated using light, which releases reactive radicals. The targeted bacteria are broken down by these reactive radicals [39]. The 3D printed SEM image of hollow microneedles is shown in Figure 22A. Figure 22B shows the smartphone-controlled wireless pumping system that is able to deliver therapeutics on demand.

9.3 MNAs based on smart systems/stimuli-responsive

An additional mechanism in the engineering of systems based on MNA for better healing of the wound is by using smart materials. These smart materials can respond to changes in the environment of the wound. Smart systems are the combination of responsiveness of active systems, which can react to the dynamic requirements of the chronic wound and user simplicity of passive release MNAs. In a recent study of this strategy, the fabrication of MNAs is from a combination of VEGF-loaded NIPAM hydrogel and antibacterial chitosan. NIPAM is temperature sensitive. The release of VEGF from the permeable hydrogel network is triggered by an increase in the temperature of a chronic inflamed wound. The lack of vascularization and bacterial infection are addressed by combining chitosan with VEGF loading. The capability of MNA to kill most of the bacteria in both E. coli and S. aureus cultures was shown in...
the antibacterial test. The MNA patch developed was applied to the rats with severely infected wounds, in which it was found that the VEGF-loaded MNA group showed the thickest granulation tissue and the most wound closure. It also demonstrated increased deposition of collagen, angiogenesis, and downregulated inflammatory response.

The MNA systems are also fabricated using bacteria-responsive smart materials to treat infected wounds [40].

Figure 23A shows the mechanism involved in release of VEGF into the wound bed with the increase in temperature during wound inflammation. (B) The mechanism involved in MNA patch action. (C) Fabricated-MNA (top) MNA which is loaded with fluorescent-labelled drugs (bottom) [40].

The MNA systems are also fabricated using bacteria-responsive smart materials to treat infected wounds [40].

Figure 23A shows the mechanism involved in release of VEGF in the wound bed with the increase in temperature during wound inflammation.

The mechanism involved in the MNA patch is shown in Figure 23B. Figure 23C shows the fabricated MNA on the top and MNA loaded with florescent loaded drugs in the bottom.

9.4 Mechanically interacting systems

The wound closures are improved by using MNAs and by the physical application of mechanical forces. The MNAs developed are to bring about mechanical interlocking after insertion due to swelling. The mechanism of interlocking by using MNAs helps
the process of healing a wound by inducing wound closure and protecting the tissue from mechanical stress. This is achieved using hybrid core-shell structured MNAs consisting of a non-swellable core and a swellable hydrogel shell. After insertion, the ISF is absorbed by the hydrogel, due to which physical entanglement is induced through the swelling of microneedle tips. There has been a significant increase in the resistance against bacterial incursion compared to surgical staples using MNA patches. The application of MNA patches has also limited the scar formation and tissue damage. The use of MNA patches also enhances the mechanical strength of tissues that are healed, which consequently reduces the susceptibility of wound reopening. The mechanism also improves both external and internal wound closure rates compared to suture application in rats. Mechanically self-interlocking needles can hold the MNA in place for a long-term drug delivery which makes them appealing. This strategy can replace the use of sutures on wounds [41].

9.5 Bioinspired design for efficient drug/vaccine coating

Biomimetics is an interdisciplinary scientific field that is aimed to solve complex technological issues. It focuses on the imitation and study of biological systems. The lateral sides of pyramidal MNs are ornamented, with European true bugs structure, facilitating an efficient and directional liquid transport. Two-photon polymerization (TPP) is used to realize this kind of MNs. To prove that these MNs pierce the skin, both ex vivo skin tests and in vivo tests were performed. The arrays of MNs can be replicated accurately using a micro-molding technique. Figure 24 shows an image depicting the idea behind biomimetics [42].

9.6 Photon-based smart bandage

Wound healing can be assessed by measuring the pH of the wound. This method is one of the most potential wound healing assessment methods. It indicates the condition and the stage of wound healing. Photons-based smart bandages for assessing wound healing present the first smart wound dressing for pH assessment. This method is based on embedded optical fiber. Optical fibers are pH sensitive and are embedded in gauze fabric and hydrocolloid wound dressing. A fiber-embedded bandage can measure pressure as low as 0.1 kPa and has high linearity in the range of 0–0.3 kPa. This is due to the low Young’s modulus of PDMS, which is the component...
of the system. The smart bandage, based on optical fiber, is capable of assessment of pressure and pH in the wound region simultaneously [42].

10. Conclusions

In this chapter, we have tried to bring out the understanding of wounds and the healing process, various types of wound healing, their causes, and how today’s technology has influenced the rate at which it heals. Microneedle-based drug delivery has played a prominent role in faster wound healing as it is capable of closely monitoring and treating the wound with no physical pain. The research related to microneedle-based wound care management is required to explore more, and we believe that it has a long and promising way to go for the welfare of humanity. Minimally invasive microneedle: a novel approach for drug delivery systems and infected wound care management is making wound healing less painful with microneedles and faster with the appropriate drug usage.

Acknowledgements

The authors of this chapter would like to acknowledge the support of the Indian Institute of Goa, India.

Conflict of interest

The authors declare no conflict of interest.

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROS</td>
<td>reactive oxygen species</td>
</tr>
<tr>
<td>MI</td>
<td>myocardial infarction</td>
</tr>
<tr>
<td>NIR</td>
<td>near infrared</td>
</tr>
<tr>
<td>GO</td>
<td>graphene oxide</td>
</tr>
<tr>
<td>PVA</td>
<td>poly vinyl alcohol</td>
</tr>
<tr>
<td>VEGF</td>
<td>vascular endothelial growth factor</td>
</tr>
<tr>
<td>MIS</td>
<td>minimally invasive surgery</td>
</tr>
<tr>
<td>PDMS</td>
<td>polydimethylsiloxane</td>
</tr>
<tr>
<td>FTIR</td>
<td>Fourier transform infrared</td>
</tr>
<tr>
<td>US</td>
<td>ultrasound</td>
</tr>
<tr>
<td>DDS</td>
<td>drug delivery systems</td>
</tr>
<tr>
<td>MNs</td>
<td>microneedles</td>
</tr>
<tr>
<td>TPP</td>
<td>two-photon polymerization</td>
</tr>
<tr>
<td>MNAs</td>
<td>microneedle array</td>
</tr>
<tr>
<td>POC</td>
<td>point of care</td>
</tr>
<tr>
<td>Zn</td>
<td>zinc nitrate</td>
</tr>
<tr>
<td>CS</td>
<td>chitosan</td>
</tr>
<tr>
<td>PACT</td>
<td>photodynamic antimicrobial chemotherapy</td>
</tr>
<tr>
<td>VEGF</td>
<td>vascular endothelial growth factor</td>
</tr>
</tbody>
</table>
Author details

Bidhan Pramanick* and Aishwarya G. Patil
IIT Goa, Goa, India

*Address all correspondence to: bidhan@iitgoa.ac.in

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
References


topical administration on full-thickness wounds in a rat model. European Journal of Pharmaceutics and Biopharmaceutics. 2022;177:61-67. DOI: 10.1016/S0039-6109(05)70575-2


[34] Liebl H, Kloth LC. Skin cell proliferation stimulated by microneedles. Journal of the American College of Clinical Wound Specialists. 2012;4(1):2-6


[38] Parisi OI, Ruffo M, Scrivano L, Malivindi R, Vassallo A, Puoci F. Smart bandage based on molecularly imprinted polymers (MIPs) for diclofenac controlled release. Pharmaceuticals. 2018;11(4):92


