International Journal of Medical and Pharmaceutical Sciences
Open access peer-reviewed Journal
Volume 2, Issue 6, Page 272-283.
https://doi.org/10.5281/zenodo.20735017

Review Article

Nanoparticles in Wound Healing: Mechanisms, Drug Delivery Strategies, and Recent Advances

Himanshi Pandey*, Shashank Tiwari, Sandhaya Kumari

Lucknow Model College of Pharmacy, Lucknow, UttarPradesh

Wound healing is a process that involves stopping bleeding, inflammation, growth and tissue repair. When wounds do not heal quickly like ulcers, burns and pressure ulcers it is a big problem for doctors. The usual ways of treating wounds often have problems like drugs not getting to the wound having to change the dressing often not being able to fight off infections and taking too long for the tissue to grow back. In the few years scientists have been looking at nanotechnology as a way to make wound healing better. Nanoparticles are very small. Have special properties that make them good for helping wounds heal. They have a surface area can get into the body easily can release drugs slowly and can target the wound directly. This makes them very useful for healing. There are kinds of nanoparticles like silver, gold, zinc oxide and polymer nanoparticles that have been shown to help wounds heal by fighting off infections reducing inflammation and helping new tissue grow. This article talks about how nanoparticles can help with healing. It looks at how they work the kinds of nanoparticles and how they can be used to treat wounds. It also talks about the challenges and safety concerns of using nanoparticles to heal wounds. The article suggests that using nanoparticles to help wounds heal is a promising way to make wounds heal faster and help patients feel better. The focus of this article is on wound healing and nanoparticles. Wound healing is a deal because it can be very slow and painful. Nanoparticles can help with healing by making it faster and more efficient. There are kinds of nanoparticles that can be used for wound healing, including silver nanoparticles and polymeric nanoparticles. These nanoparticles can help with wounds, like diabetic ulcers and can even help with tissue regeneration.

Keywords: Wound Healing, Nanoparticles, Nanotechnology, Drug Delivery Systems, Silver Nanoparticles, Polymeric Nanoparticles, Chronic Wounds, Tissue Regeneration.

INTRODUCTION

Wound healing is a process that helps fix damaged tissues. It has phases:

* Hemostasis
* Inflammation
* Proliferation
* Remodeling.

These phases work together to restore the skin. Wound healing is crucial for keeping skin healthy and preventing infections. Some wounds, like ulcers, pressure ulcers and burn wounds take a long time to heal. This is often because of inflammation, infections and poor tissue repair. Wound healing is important for ulcers and also for pressure ulcers and burn wounds. these types of wounds need care to heal quickly and prevent further problems. The wound healing process can be slow for people with diabetes. also, for those, with pressure ulcers and burn wounds. The usual ways we treat wounds like using creams and antibiotics and dressing the wound do not work well. These methods have problems like the medicine not getting deep into the wound needing to be applied a lot and not helping the wound heal properly. so, we really need to find ways to help wounds heal and fix damaged tissue. The old ways are not good enough so we have to come up with ideas, for treating wounds like new ways to help the wound repair itself and grow new tissue. Nanotechnology is really helping with wound care. It

does a job of getting drugs to where they are needed fighting off bad germs and helping the body fix damaged tissue. Tiny particles like silver, gold, zinc oxide and special kinds of fat particles are very good at helping wounds heal faster. They do this by giving the body the amount of medicine at the right time and targeting the bad things that are making the wound sick. This article is, about how these tiny particles help wounds heal, how they work, what they can be used for what is new what is hard and what we can expect in the future. Wound healing is a process that fixes damaged tissues after we get hurt. It is very complicated. Has many steps, like stopping the bleeding getting rid of the bad stuff making new tissue and making the tissue strong again. All these steps work together to make the tissue whole again. We need wound healing to keep our skin healthy and to prevent germs from getting in Some things, like diabetes, infections, poor blood flow, getting older and stress can make it hard for wounds to heal and that can lead to chronic wounds that never heal. Chronic wounds, like diabetic foot ulcers, pressure ulcers and burn wounds are a problem for healthcare all over the world. These wounds can get infected, take a time to heal and are very expensive to treat. The ways we usually take care of wounds like using medicine on the wound, antibiotics and bandages do not always work well. The medicine might not get deep into the wound it might break down fast or we might need to put it on the wound too often. So, we need to find better ways to help wounds heal. Nanotechnology is a field that combines many areas of science and has many uses like helping us deliver medicine to the right place in the body. Nanoparticles are small things that are between 1 and 1000 nanometers in size. They have properties, like a big surface area that help them work well. These properties help nanoparticles get past the problems of treatments and make them work better. Many kinds of nanoparticles like silver, gold and zinc oxide have shown that they can help wounds heal. These tiny particles can deliver medicine right to the wound release it slowly kills germs reduce swelling help new blood vessels grow and make the tissue heal faster. People are also looking at using nanoparticles to make kinds of bandages and ways to deliver medicine that can help create a good environment for the wound to heal. New discoveries in nanotechnology have led to the creation of ways to use nanoparticles to help wounds heal. These new ways are safer. Work better, than what we have now. So, people are studying nanoparticles a lot to see if they can be used to heal wounds. This article will talk about how nanoparticles can help with healing what kinds of nanoparticles there are, how they work, what they can be used for what is new what problems there are and what the future might hold for using nanoparticles to help wounds heal. The skin is the part of the human body and it helps keep us safe from getting hurt by things outside. When the skin gets damaged because of an accident, a burn or an operation it starts a process to fix itself. This process is called healing and it is very important for our body to work properly. Wound healing is when our body works to fix the damaged skin by using different types of cells, special helpers and signals. With a lot of progress in taking care of wounds, it is still very hard to deal with wounds that do not heal and get infected. Many people around the world have problems with wounds that do not heal which can make them very sick keep them in the hospital for a time and cost a lot of money. Also, many people have diabetes, which can cause wounds on their feet that're very hard to heal and can even lead to losing a foot. One of the problems with wounds is when they get infected with bad germs. When this happens, it can take longer for the wound to heal and can even stop it from healing all. Also, when there are many bad chemicals in the wound it can be hard for new blood vessels to grow and for the wound to get the nutrients it needs. So, to make a wound heal we need to get rid of the infection and help the skin fix itself. Recently scientists have found that something called nanotechnology can be very helpful in healing wounds. Nanotechnology is when we make small things that can interact with our body and help it heal. These small things, called nanoparticles are very good at helping our body because they are so small and can work well with our cells. Nanoparticles are very helpful in healing wounds because they can make medicines work better help them get to the place and make them last longer. This means that the medicine can stay in the wound for a time and help it heal, which makes the treatment work better and is easier for the patient. Also, nanoparticles can get into the skin easily and help the cells take in the medicine. Some nanoparticles, like silver ones are very good at killing germs. Gold nanoparticles can help reduce inflammation and oxidative stress, which can help the skin heal. Zinc

oxide nanoparticles can also kill germs and help the skin heal. Other nanoparticles, like ones made from polymers or lipids can carry medicines, special helpers, proteins and genetic material to the wound. Putting nanoparticles into bandages, gels and scaffolds can also help wounds heal. These special bandages can keep the wound clean help it breathes and give it the medicine it needs which can help it heal faster. Even though nanoparticles can be very helpful in healing wounds there are still some problems to solve. We need to make sure they are safe do not hurt us and can be made in quantities. We also need to make sure they work well in people and are approved by the government. So, scientists need to keep studying nanoparticles to make them work better and safer. In the few years we have learned a lot, about how nanoparticles can help wounds heal. Because of this nanoparticle are becoming a promising way to deliver medicines and help wounds heal. This article will talk about the types of nanoparticles how they work what they can do and what we can expect from them in the future.

Physiology of wound healing activity:

Wound healing is a process that helps our body fix damaged tissues. It is a detailed process that involves many different steps. The wound healing process can be divided into four parts: the hemostasis phase, the inflammation phase, the proliferation phase and the remodeling phase. These parts work together to help our body heal.

1. Hemostasis Phase

The hemostasis phase is what happens right after we get hurt. It starts a few minutes after we get a wound. The main goal of this phase is to stop the bleeding and get everything for the rest of the healing process. When we get hurt our blood vessels get smaller to reduce blood flow to the damaged area. Then special cells called platelets go to the damaged area and form a clot. This clot is like a patch that helps our body start the healing process. The platelets also release helpers like platelet-derived growth factor transforming growth factor-beta and vascular endothelial growth factor. These helpers are very important for healing. The clot that forms during the hemostasis phase acts like a matrix that helps our cells move around and start the healing process.

2. Inflammatory Phase

The inflammatory phase usually starts a hours after we get hurt and can last for several days. This phase is very important because it helps our body get rid of bacteria and damaged cells. It also gets the wound ready for the step in the healing process. The first cells to go to the wound are called neutrophils. They eat up bacteria and damaged cells and they also release special substances that help fight infection. Then other cells called macrophages take over. They help clean up the wound, release helpers and get everything ready for the next step in the healing process. There are special helpers like interleukins, tumor necrosis factor-alpha and chemokines that help regulate this phase. We need some inflammation to heal. Too much can cause problems and delay the healing process.

3. Proliferative Phase

The proliferative phase usually starts a days after we get hurt and can last for a few weeks. This is when our body starts to build tissue and close the wound. It involves different steps like fibroblast proliferation, collagen synthesis, angiogenesis, granulation tissue formation and re-epithelialization. Fibroblasts are cells that go to the wound and start making tissue. They make a protein called collagen that gives the new tissue strength. At the time new blood vessels form, which helps get oxygen and nutrients to the new tissue. Other cells called keratinocytes start to grow and move across the wound, which helps close the wound and restore the skin barrier. The formation of tissue is a sign that this phase is working well.

4. Remodeling Phase

The remodeling phase is the step in the wound healing process. It can take months or even years. During this phase the new tissue gets stronger and more organized. The collagen in the tissue changes which makes it stronger. The cells that were helping to build the tissue start to slow down and unnecessary blood vessels disappear. The tissue is constantly being remodelled, which helps it get stronger. Even though the healed tissue gets much stronger it is rarely as strong as it was before we got hurt. Usually it gets to be 70-80% as strong as normal tissue. Wound healing is the process that helps our body fix damaged tissues.

It is a detailed process that involves many different steps, including the hemostasis phase the inflammation phase, the proliferation phase and the remodeling phase. Wound healing is what helps our body fix wounds and get back, to normal.

3. Problems Associated with Conventional Wound Treatment:

Conventional wound treatment methods like gauze dressings and bandages have been used for a time to manage wounds. These methods provide some protection. Help control infection. However, they have limitations that can slow down the healing process. This is why researchers are working on better ways to treat wounds especially using tiny particles.

1. Drugs Do Not Reach Enough

Many creams and ointments used on wounds do not penetrate deep enough into the tissue. As a result, the medicine does not reach the place in the right amount, which makes the treatment less effective and the healing process longer.

2. Need to Apply Medicine

Traditional dressings and creams need to be applied many times because the medicine is released quickly and does not stay on the wound for long. This can be uncomfortable for the patient. Make them less likely to follow the treatment.

3. Risk of Infection

Open wounds can easily get infected with bacteria. The medicines used to prevent infection do not always work for a time. Also, many bacteria are becoming resistant to antibiotics, which makes them less effective.

4. Not Enough Moisture

Wounds need to be kept moist to heal properly. Traditional dressings like cotton gauze can absorb much liquid from the wound, which can delay healing. On the hand too much moisture can lead to infection.

5. Slow Healing of Chronic Wounds

People with diabetes blood vessel problems or burns often have wounds that heal slowly. Conventional treatments do not always address the underlying issues, such as inflammation and poor blood flow, which can delay healing.

6. Medicine is Not Released Properly

Most traditional wound care products release the medicine at once after application. This can lead to much medicine at first and not enough later on which means the medicine needs to be applied again and again.

7. Damage to Healthy Tissue

Some antiseptics and antibiotics can harm cells that are trying to repair the wound. Using many antibiotics can also lead to allergic reactions and disrupt the normal healing process.

8. Patients Do Not Like the Treatment

dressing changes, pain, bad smell and long treatment times can make patients unhappy and less likely to follow the treatment, especially those with chronic wounds.

9. Limited Ability to Help Tissue Regenerate

Conventional treatments mainly focus on covering the wound and preventing infection than helping the tissue regenerate. They do not always promote the growth of cells and tissue.

10. Scarring and Cosmetic Issues

Traditional wound treatments do not always ensure that the wound heals with scarring. This can lead to scarring, thickening of tissue and poor cosmetic results. Wound treatment should not focus on healing the wound but also on making sure it looks as good, as possible after it heals.

4. Classification of Nanoparticles Used in Wound Healing:

Nanoparticles are really materials that are usually between 1 and 1000 nm in size. They have some properties that make them useful for helping wounds heal. These properties include a surface area, the

ability to get into the body easily and the ability to release drugs in a controlled way. Because of these properties nanoparticles are being used more and more to help wounds heal. There are a few types of nanoparticles that are used in wound healing. These include nanoparticles, polymeric nanoparticles, lipid-based nanoparticles and natural polymer nanoparticles.

1. Metallic Nanoparticles

Metallic nanoparticles are one of the studied types of nanoparticles for wound healing. This is because they have antimicrobial, anti-inflammatory and regenerative properties.

1.1 Silver Nanoparticles

Silver nanoparticles are the commonly used nanoparticles for wound healing. They are really good at killing a range of bacteria, fungi and viruses. They work by interacting with the cell membranes of microbes creating oxygen species and disrupting DNA replication. This leads to the death of the microbe. When it comes to wound healing silver nanoparticles help to reduce infection decrease inflammation and promote tissue regeneration. Because of these properties they are often used in dressings, hydrogels and nanofiber systems.

The advantages of nanoparticles include:

* Strong antimicrobial activity
* Prevention of biofilm formation
* Enhanced wound closure
* Reduced infection risk

1.2 Gold Nanoparticles

Gold nanoparticles are also being used in healing. They have biocompatibility and unique optical properties. They also have anti-inflammatory effects that help to accelerate wound healing. Gold nanoparticles help to stimulate the growth of tissue which is important for wound healing. Gold nanoparticles can also be used to deliver drugs to the wound site. They can carry growth factors, peptides and other therapeutic agents that are used to treat wounds.

1.3 Zinc Oxide Nanoparticles

Zinc oxide nanoparticles have antioxidant and tissue regenerative properties. Zinc is an element that is involved in the synthesis of collagen the growth of new tissue and the functioning of the immune system. Zinc oxide nanoparticles help to enhance wound healing by reducing growth stimulating cell proliferation and promoting the formation of new tissue. They are often used in dressings and topical formulations.

2. Nanoparticles

Polymeric nanoparticles are tiny systems that are made from biodegradable and biocompatible polymers. They can be used to deliver agents to the wound site in a controlled and sustained way. There are a few types of polymeric nanoparticles including:

2.1 Nanospheres

Nanospheres are systems in which the drug is dispersed throughout the polymer matrix. The drug is released as the polymer breaks down.

2.2 Nanocapsules

Nano capsules have a shell that surrounds a core of drug. This helps to protect the drug and deliver it to the place. Some common polymers that are used to make polymeric nanoparticles include:

* Poly (lactic acid)
* Poly (lactic-co-glycolic acid)
* Polycaprolactone
* Polyethylene glycol

The advantages of nanoparticles include:

* Controlled drug release
* Enhanced drug stability
* Reduced toxicity
* Improved therapeutic efficacy

Polymeric nanoparticles have been used to deliver a range of agents to the wound site, including antibiotics, anti-inflammatory drugs, growth factors and herbal compounds.

3. Lipid-Based Nanoparticles

Lipid nanoparticles are made from lipids and are being used more and more in wound healing. This is because they have biocompatibility and can carry a lot of drugs.

3.1 Solid Lipid Nanoparticles

Solid lipid nanoparticles are made from lipids that are stabilized by surfactants. They provide controlled drug release, improved stability and enhanced skin penetration. Solid lipid nanoparticles have been used to deliver anti-inflammatory agents to the wound site.

3.2 Nanostructured Lipid Carriers

Nanostructured lipid carriers are a type of lipid nanoparticle. They are made from a mixture of liquid lipids, which helps to increase the amount of drug that they can carry. Nanostructured lipid carriers help to enhance drug penetration into the wound tissue and provide therapeutic effects. The advantages of lipid nanoparticles include:

* Excellent biocompatibility
* Drug release
* Increased drug stability
* Wound penetration

4. Hybrid Nanoparticles

Hybrid nanoparticles combine two or more nanomaterials to achieve properties. For example, metallic nanoparticles can be incorporated into matrices to provide antimicrobial activity and controlled drug release.

4.1 Hybrid nanoparticles offer:

* Improved therapeutic efficacy
* Enhanced stability
* Multifunctional wound healing action
* Targeting ability

Overall nanoparticles have a lot of potential, for wound healing. They can be used to deliver agents promote tissue regeneration and enhance wound closure. Different types of nanoparticles have properties and advantages and they can be used in a range of wound healing applications.

5. Nanoparticles and Wound Healing:

Nanoparticles help wounds heal by doing a few things. They can stop germs from growing reduce swelling and help new tissue grow. Because of their size nanoparticles can easily talk to the cells and other things at the wound site. This helps nanoparticles make the wound healing process go faster and work better.

1. Stopping Germs

One-way nanoparticles help wounds heal is by stopping germs from growing. When germs get into a wound they can make it hard for the wound to heal. Some nanoparticles, like nanoparticles, gold nanoparticles and zinc oxide nanoparticles are really good at stopping germs. They do this by:

* Breaking down the germs layer
* Making bad things that hurt the germ
* Making the germs insides leak out
* Stopping the germ from making proteins
* Hurting the germs DNA. Stopping it from making more germs

This helps keep the wound clean and makes it easier for it to heal.

2. Reducing Swelling

Swelling is a part of the healing process. If it goes on for too long it can make it hard for the wound to heal. Nanoparticles can help control swelling by:

* Reducing the amount of things that make swelling worse
* Helping the cells that fix wounds work better
* Reducing stress on the cells
* Stopping things that make swelling

This helps the wound start to heal and makes it stronger.

3. Helping Tissue Grow

Sometimes wounds can get many bad things that can hurt them. Some nanoparticles can help stop these things and keep the tissue safe. Gold nanoparticles and some other kinds of nanoparticles are good at this.

They help by:

* Keeping cells safe
* Reducing stress on the cells
* Helping cells survive
* Helping tissue grow

3. Delivering Medicine

Nanoparticles can carry medicine right to the wound. Because they're so small they can:

* Get deep into the wound
* Keep the medicine from breaking down
* Release the medicine over time
* Take the medicine right to the cells that need it

This helps the medicine work better. Makes it easier to take.

4. Helping New Blood Vessels Grow

New blood vessels are important for healing wounds. Nanoparticles can help make blood vessels by:

* Helping the cells that make blood vessels grow
* Making more of the things that help blood vessels grow
* Getting blood to the wound

This helps the wound get the oxygen and food it needs to heal.

5. Helping New Tissue Grow

Nanoparticles can help new tissue grow by:

* Helping the cells that make tissue move
* Helping the cells that make new tissue grow
* Making more of the things that help new tissue grow
* Helping the new tissue get strong

This makes the wound stronger. Helps it heal.

6. Helping the Skin Heal

The skin is the layer of the body. Nanoparticles can help the skin heal by:

* Helping the cells that make new skin grow
* Helping the cells that make skin move
* Helping the cells talk to each

This helps the skin get back to normal and keeps the wound safe.

7. Keeping the Wound Clean

Nanoparticles can help keep the wound clean by:

* Keeping it moist
* Letting oxygen in
* Absorbing liquid
* Keeping germs out

This helps the wound heal. Makes it stronger.

8. Helping the Tissue Get Strong

Nanoparticles can help the new tissue get strong by:

* Helping the cells that make new tissue grow
* Helping the new tissue get the things it needs
* Making the new tissue strong

This makes the wound heal. Makes it strong. Nanoparticles help wounds heal by doing all these things. They are very helpful for making wounds get better. Nanoparticles are good, at helping wounds heal because they can do many things.

6. Nanoparticle-Based Drug Delivery Systems in Wound Healing:

Nanoparticle-based drug delivery systems are a way to treat wounds. Old ways of treating wounds often did not work well because the medicine did not get into the wound it broke down fast and it had to be given many times. Nanoparticle-based systems are better because they can deliver the medicine right to the wound the medicine lasts longer. It is released slowly. The small size of nanoparticles lets them get into the wound and deliver the medicine where it is needed. This is a deal in medicine because it helps the wound heal faster and with fewer problems.

Advantages of Nanoparticle-Based Drug Delivery Systems

Using nanoparticles to deliver medicine has good things about it like:

* The medicine is released slowly over time
* The medicine lasts longer
* It gets into the body better

* It goes right to the wound
* You do not have to take it often
* Patients are more likely to take their medicine
* It fights germs better
* It helps the tissue grow back
* It is less harmful to the body

1. Polymeric Nanoparticle-Based Drug Delivery Systems

Polymeric nanoparticles are made from materials that are safe for the body. These nanoparticles can hold medicine, proteins and other helpful things.

When we use these nanoparticles to treat wounds, they are very helpful because:

* They release the medicine slowly
* They keep the medicine from breaking down
* They help the medicine stay in the wound
* They help the medicine get into the tissue

We have used these nanoparticles to deliver antibiotics, anti-inflammatory medicines, growth factors and herbal extracts to help wounds heal.

2. Lipid-Based Nanoparticle Drug Delivery Systems

Lipid nanoparticles are used a lot because they are safe for the body and can get into the skin easily.

a) Solid Lipid Nanoparticles (SLNs)

SLNs are made from fats and special helpers. They release the medicine slowly over time. The good things about SLNs are:

* The medicine lasts longer
* It gets into the wound better
* The medicine is released slowly
* The medicine does not break down fast

b) Nanostructured Lipid Carriers (NLCs)

NLCs are made from a mix of solid and liquid fats. They can hold medicine than SLNs. The good things about NLCs are:

* They can hold medicine
* The medicine gets into the body better
* The medicine lasts longer

3. Metallic Nanoparticle-Based Drug Delivery Systems

Metallic nanoparticles are special because they can fight germs and deliver medicine. Silver Nanoparticles (AgNPs) Silver nanoparticles are used a lot to treat wounds because they can fight kinds of germs. They work by:

* Breaking down the germs layer
* Stopping the germ from growing
* Keeping the germs from forming a layer

Using silver nanoparticles in wound dressings helps prevent infection and makes the wound heal faster. Gold Nanoparticles (AuNPs) Gold nanoparticles can reduce inflammation. Fight free radicals. They can also carry molecules.

They help by:

* Making cells grow
* Making collagen
* Helping new blood vessels form

4. Nanogel-Based Drug Delivery Systems

Nanogels are very small. Can hold a lot of water. They are very helpful for delivering medicine to wounds. The good things about nanogels are:

* They can hold a lot of medicine
* They keep the wound moist
* They release the medicine slowly
* They are safe for the body

Nanogels are very good at delivering antibiotics, peptides and growth factors right to the wound.

5. Liposome-Based Drug Delivery Systems

Liposomes are like balls that can hold medicine. They are made from fats and can carry many kinds of medicine. The good things about liposomes are:

* They can carry medicine that does not mix with water
* They reduce the harm of the medicine
* They release the medicine slowly
* They help the medicine get to the place

Liposomes are used a lot to deliver antimicrobial and anti-inflammatory medicines to wounds.

6. Nano Emulsion-Based Drug Delivery Systems

Nano emulsions are like mixtures of oil, water and special helpers. They are very small. Can carry medicine. The good things about nano emulsions are:

* They can carry medicine that does not mix with water
* They help the medicine get into the skin
* They are more stable
* They help the medicine get into the body

Nano emulsions have been shown to be very helpful in delivering extracts and antimicrobial agents to wounds. [43]

7. Nanofiber-Based Drug Delivery Systems

Nanofibers are made using machines and are like the tissue in our body. The good things about nanofibers are:

* They have a surface area
* They let oxygen in
* They release the medicine slowly
* They help cells grow and attach

Nanofiber dressings help the tissue grow back and make the wound heal faster.

8. Hybrid Nanoparticle Systems

Hybrid nanoparticle systems are made by combining materials. They can do things at once. Examples include: [44]

* Silver nanoparticles, in gels
* Polymeric-lipid hybrid nanoparticles
* Metal-polymer composite nanoparticles These systems are very helpful because they:
* Fight germs
* Release the medicine slowly
* Help the wound heal faster

7. Recent Advances in Nanoparticle-Mediated Wound Healing:

Nanotechnology has really changed the way we manage wounds. It has led to the development of treatments that use tiny particles called nanoparticles. These particles can help wounds heal faster and better. Researchers have been working on creating nanoparticles that can do things at once like fight infections deliver medicine help tissue grow back and monitor the wound. People have been studying nanoparticles that are loaded with growth factors. These nanoparticles help the body make blood vessels and repair tissues by giving it the things it needs over a long period of time. Nanoparticles that work with stem cells are also being used to help heal wounds. They do this by helping the cells in the wound survive and by fixing the tissue. Now we have nanoparticles that are made in a way that's safe for the environment. This makes the treatments that use nanoparticles even safer for people to use. There are also kinds of nanoparticles that can change what they do based on what is happening around them. We have nanostructured lipid carriers and systems that can deliver genes to cells. These new technologies can help us give people the treatment they need for their wound. They can also help reduce the effects of the treatment and make it work better. So, it seems like nanoparticles are going to be very helpful in the future for healing wounds and helping the body repair itself. Nanoparticles are really good, at helping the body heal wounds. Fix damaged tissues. They are a part of new ways to take care of wounds and help the body fix itself.

1. Smart Nanoparticle-Based Wound Dressings

One big advance in healing is the development of smart wound dressings that use nanoparticles. These dressings can react to changes in the wound like pH, temperature and moisture. They can even detect if there’s an infection.

Smart nanoparticle dressings can:

* Detect wound infection
* Release drugs in a controlled way
* Keep the wound moist
* Help tissue grows back

These systems provide care and reduce the need for frequent dressing changes.

2. Silver Nanoparticle-Integrated Advanced Dressings

Silver nanoparticles are still one of the studied materials in wound management. Recent developments have focused on incorporating nanoparticles into hydrogels, nanofibers and bioengineered wound dressings.

These advanced systems provide:

* Antimicrobial activity
* Prevention of biofilm formation
* Reduced inflammation
* Faster wound closure

Silver nanoparticle-loaded dressings have shown efficacy against multidrug-resistant microorganisms.

3. Nanoparticle-Loaded Hydrogels

Hydrogels combined with nanoparticles are effective wound healing platforms. They provide an environment and deliver therapeutic agents directly to the wound.

Recent nanoparticle-loaded hydrogels offer:

* Drug retention
* Controlled release profiles
* Improved cell proliferation
* Increased angiogenesis

These formulations are particularly useful for diabetic wound healing and burn wound management.

4. Growth Factor-Loaded Nanoparticles

Growth factors play a role in tissue regeneration. Nanoparticle-based delivery systems protect growth factors from degradation. Ensure their sustained release.

Delivered growth factors include:

* Vascular Endothelial Growth Factor (VEGF)
* Epidermal Growth Factor (EGF)
* Platelet-Derived Growth Factor (PDGF)
* Basic Fibroblast Growth Factor (bFGF)

These systems enhance angiogenesis, collagen synthesis and tissue remodeling.

5. Stem Cell-Associated Nanoparticle Therapies

Recent studies have investigated the combination of nanoparticles with stem cell therapy. Nanoparticles improve stem cell survival, cellular targeting, growth factor secretion and tissue regeneration. This approach has shown results in the treatment of chronic and non-healing wounds.

6. Nanofiber-Based Drug Delivery Systems

Electro spun nanofibers integrated with nanoparticles represent an important advancement in wound care. Their structure closely resembles the extracellular matrix and supports cellular attachment and proliferation.

Advantages include:

* Drug-loading capacity
* Sustained drug release
* Excellent oxygen permeability
* Enhanced tissue regeneration

Nanofiber systems have demonstrated effectiveness in accelerating wound healing.

7. Green-Synthesized Nanoparticles

The development of eco- green-synthesized nanoparticles has gained attention. These nanoparticles are produced using plant extracts, microorganisms or natural biomolecules.

Benefits include:

* Reduced toxicity
* Improved biocompatibility
* Cost- production
* Environmentally sustainable synthesis

Green silver and gold nanoparticles have shown remarkable antimicrobial and wound healing activities.

8. Nanostructured Lipid Carriers and Solid Lipid Nanoparticles

Advanced lipid-based nanocarriers have been explored for healing applications. Recent formulations provide:

* Drug stability
* Enhanced skin penetration

* Controlled release behavior
* Increased bioavailability

These systems are effective for delivering soluble drugs and bioactive compounds.

CONCLUSION:

Wound healing is a process. It needs different cells and molecules to work together to fix damaged tissues. With regular wound treatments there are still problems like infections, slow healing and not enough tissue growth. These problems have led to the development of wound care methods using nanotechnology. Nanoparticles are particles that can help with wound healing. They have properties that make them useful. These include being very small having a surface area and being able to release drugs slowly. Different types of nanoparticles such as silver, gold and zinc oxide have shown promise in helping wounds heal. They can fight infections reduce inflammation and promote tissue growth. Nanoparticle-based systems for delivering drugs have also shown promise. These include nanogels, nanofibers and liposomes. They can help make drugs more stable release them slowly and promote tissue growth. New developments like wound dressings and nanoparticles that respond to stimuli have further expanded the use of nanotechnology, in wound care. Overall using nanoparticles to help wounds heal is an effective approach. It can be used to treat both chronic wounds. There are still challenges to overcome, such as toxicity and production costs. Ongoing research and technological advancements are expected to solve these problems. Nanoparticle-based wound healing systems offer healing rates, reduced complications and better patient outcomes. They hold promise for the future of regenerative medicine and advanced wound care. Nanoparticles will play a role in this. Nanoparticle research is ongoing. Nanoparticles are showing promise in helping wounds heal faster. They have some cool properties that make them useful. They can deliver medicine to the wound in a targeted way. they can release medicine slowly over time. they can fight off infections. they can even help tissue grow back. Many types of nanoparticles are being studied. These include silver, gold, zinc oxide, polymeric and lipid nanoparticles. They have all shown to be pretty effective in helping wounds heal faster and reducing infections. New developments in nanoparticle medicine delivery and smart wound dressings are also improving treatment results. There are still some concerns about safety, toxicity and getting them approved for use in humans. Despite these challenges nanoparticles could play a role in the future of wound care and regenerative medicine. Nanoparticles are really exciting for wound care and regenerative medicine. The use of nanoparticles, in medicine is an area that holds a lot of potential.

REFERENCES

1. Kumar M, Mahmood S, Chopra S, Bhatia A. Biopolymer based nanoparticles and their therapeutic potential in wound healing - A review. International Journal of Biological Macromolecules. 2024; 267:131335.
2. Zhao J, Li T, Yue Y, et al. Advancements in employing two-dimensional nanomaterials for enhancing skin wound healing: a review of current practice. Journal of Nanobiotechnology. 2024; 22:520.
3. Sharda D, Attri K, Choudhury D. Greener healing: sustainable nanotechnology for advanced wound care.Discover Nano. 2024; 19:127.
4. Nasra S, Pramanik S, Oza V, et al. Advancements in wound management: integrating nanotechnology and smart materials for enhanced therapeutic interventions. Discover Nano. 2024; 19:159.
5. Chen S, Wang Y, Bao S, et al. Cerium oxide nanoparticles in wound care: a review of mechanisms and therapeutic applications. Frontiers in Bioengineering and Biotechnology. 2024; 12:1404651.
6. Hamed SH, Azooz EA, Al-Mulla EAJ. Nanoparticles-assisted wound healing: A review. Nano Biomedicine and Engineering. 2023;15(4):425–435.
7. Dam P, Celik M, Ustun M, et al. Wound healing strategies based on nanoparticles incorporated in hydrogel wound patches. RSC Advances. 2023; 13:21345–21364.
8. Sharda D, Kaur P, Choudhury D. Protein-modified nanomaterials: emerging trends in skin wound healing. Discover Nano. 2023; 18:127.

9. Nanoparticle-based therapeutic approaches for wound healing: a review of the state-of-the-art. Materials Today Chemistry. 2023; 27:101319.
10. Liang H, Ao Y, Li W, et al. Multifunctional biomaterials and nanotechnology strategies for wound healing. Bioactive Materials. 2023; 22:453–478.
11. Pang Q, Jiang Z, Wu K, Hou R, Zhu Y. Nanomaterials-Based Wound Dressing for Advanced Management of Infected Wound. Antibiotics. 2023;12(2):351.
12. Dam P, Celik M, Ustun M, et al. Wound healing strategies based on nanoparticles incorporated in hydrogel wound patches. RSC Advances. 2023; 13:21345–21364.
13. Hamed SH, Azooz EA, Al-Mulla EAJ. Nanoparticles-assisted Wound Healing: A Review. Nano Biomedicine and Engineering. 2023;15(4):425–435.
14. Sharda D, Kaur P, Choudhury D. Protein-modified nanomaterials: Emerging trends in skin wound healing. Discover Nano. 2023; 18:127.
15. Kumar M, Mahmood S, Chopra S, Bhatia A. Biopolymer based nanoparticles and their therapeutic potential in wound healing - A review. International Journal of Biological Macromolecules. 2024; 267:131335.
16. Chen S, Wang Y, Bao S, et al. Cerium oxide nanoparticles in wound care: A review of mechanisms and therapeutic applications. Frontiers in Bioengineering and Biotechnology. 2024; 12:1404651.
17. Nasra S, Pramanik S, Oza V, et al. Advancements in wound management: Integrating nanotechnology and smart materials for enhanced therapeutic interventions. Discover Nano. 2024; 19:159.
18. Zhao J, Li T, Yue Y, et al. Advancements in employing two-dimensional nanomaterials for enhancing skin wound healing. Journal of Nanobiotechnology. 2024.
19. Sharda D, Attri K, Choudhury D. Greener healing: Sustainable nanotechnology for advanced wound care. Discover Nano. 2024.
20. Liang H, Ao Y, Li W, et al. Multifunctional biomaterials and nanotechnology strategies for wound healing. Bioactive Materials. 2023; 22:453–478.
21. Boateng J, Catanzano O. Advanced therapeutic dressings for effective wound healing – A review. Journal of Pharmaceutical Sciences.
22. Ahmed T, Shahid M, Noman M. Silver nanoparticles: Synthesis, biological applications and wound healing potential. Materials Science and Engineering C.

Cite: Himanshi Pandey*, Shashank Tiwari, Sandhaya Kumari, Nanoparticles in Wound Healing: Mechanisms, Drug Delivery Strategies, and Recent Advances, Int. J. Med. Pharm. Sci., 2026, 2 (6), 272-283. https://doi.org/10.5281/zenodo.20735017