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Bacterial Cellulose-Based Drug Delivery Systems: Recent Advances in Wound Healing and Tissue Regeneration

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Abstract : *Bacterial cellulose is a natural substance produced by certain bacteria. Nowadays, it is getting more attention in the pharmaceutical field because of its useful properties. It has good water-holding capacity, is safe for the human body and helps in the wound healing process. Due to these properties, bacterial cellulose can be used in wound dressings and drug delivery systems.*

• Researchers are studying the use of bacterial cellulose for delivering different drugs, such as antibiotics and antibacterial agents, directly to the affected area. It helps maintain moisture around the wound and provides a suitable environment for the growth of new skin cells. It may also help in preventing infection and improving the healing process. Bacterial cellulose-based materials have shown promising results in the treatment of burns, diabetic wounds and other skin injuries.

This review mainly focuses on the properties, preparation and pharmaceutical applications of bacterial cellulose-based drug delivery systems. It also highlights their role in wound healing, tissue regeneration, recent developments, limitations and future possibilities in the medical and pharmaceutical fields.

Keywords: Bacterial Cellulose, Drug Delivery System, Wound Healing, Tissue Regeneration, Antibiotics, Wound Dressing.

I. INTRODUCTION

Wound healing is a natural process in which the body repairs damaged skin and tissues. Wounds may occur due to accidents, burns, surgery, infections or other injuries. Normally, small wounds heal within a few days, but some wounds, such as diabetic wounds and chronic wounds, take a long time to heal. In such cases, proper wound care and suitable treatment are very important to prevent infection and support faster healing.

In recent years, researchers have been studying different materials that can help in wound healing. One such material is bacterial cellulose. It is a natural substance produced by certain bacteria during their growth. Bacterial cellulose looks similar to a thin white sheet or gel-like material. It has some useful properties, such as high water absorption, good strength, flexibility and biocompatibility. These properties make it useful for different pharmaceutical and medical applications.

Bacterial cellulose is different from normal plant cellulose because it does not contain lignin, hemicellulose and other plant materials. Due to its special structure, it can hold a large amount of

water and maintain a moist environment around the wound. This helps in creating suitable conditions for wound healing and the growth of new skin cells.

Another important use of bacterial cellulose is in drug delivery systems. Medicines such as antibiotics and other antibacterial agents can be added to bacterial cellulose materials. These materials can help deliver medicines directly to the affected area and release them slowly over a period of time. This may help control infection and improve the wound healing process.

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Bacterial cellulose is also being studied for tissue regeneration because it provides a suitable surface for cell growth. It has potential applications in skin repair, burn treatment and the management of chronic wounds. Researchers are also developing bacterial cellulose-based materials by combining them with nanoparticles, polymers and other substances to improve their properties.

Therefore, bacterial cellulose has become an interesting material in pharmaceutical research. This review article discusses its preparation, properties, drug delivery applications and recent developments, with special focus on wound healing and tissue regeneration.

II. STRUCTURE AND PROPERTIES OF BACTERIAL CELLULOSE

2.1 Structure of Bacterial Cellulose

Bacterial cellulose is a natural polymer made up of glucose molecules. These glucose molecules are connected together to form long chains. Several chains combine to form very small fibres called nanofibres. These nanofibres form a three-dimensional network structure.

Bacterial cellulose has a structure similar to plant cellulose, but it is produced by bacteria. It does not contain lignin, hemicellulose or other unwanted plant materials. Because of its fine fibre structure, it can absorb and hold a large amount of water. Its network structure also provides good strength and flexibility.

2.2 Properties of Bacterial Cellulose

Bacterial cellulose has several important properties that make it useful in pharmaceutical and medical applications.

1. High Water-Holding Capacity:

Bacterial cellulose can absorb and hold a large amount of water. This helps maintain moisture around the wound and supports the healing process.

2. Biocompatibility:

It is generally well tolerated by the human body. It can come in contact with skin and tissues without causing major harmful effects.

3. High Purity:

Bacterial cellulose is produced by bacteria and does not contain lignin or hemicellulose. Therefore, it has a relatively pure structure.

4. Good Mechanical Strength:

It has good strength and flexibility. This makes it suitable for preparing wound dressings and other medical materials.

5. Porous Structure:

Bacterial cellulose has a network of very small fibres with spaces between them. This structure helps in holding water and loading different medicines.

6. Biodegradability:

Bacterial cellulose has the potential to break down under suitable conditions. However, it is not easily degraded by enzymes present in the human body.

7. Drug-Loading Capacity:

Its network structure allows different medicines and active substances to be added. These include antibiotics, antibacterial agents and other therapeutic compounds.

8. Non-Toxic Nature:

Pure bacterial cellulose is generally considered non-toxic and suitable for biomedical applications when properly prepared and tested.

These properties make bacterial cellulose a promising material for drug delivery, wound dressings and tissue regeneration.

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III. PRODUCTION AND PREPARATION OF BACTERIAL CELLULOSE

Bacterial cellulose is produced by certain types of bacteria during their growth. These bacteria use glucose and other nutrients present in the culture medium to produce cellulose. The production process is carried out under controlled conditions in a laboratory.

3.1 Microorganisms Used for Production

Different types of bacteria can produce bacterial cellulose. Some commonly used microorganisms are:

1. Komagataeibacter xylinus
2. Komagataeibacter hansenii
3. Komagataeibacter rhaeticus
4. Gluconacetobacter species

Among these, Komagataeibacter xylinus is one of the most commonly used bacteria for bacterial cellulose production.

3.2 Methods of Production

Bacterial cellulose is mainly produced by two methods:

1. Static Cultivation Method

In this method, bacteria are grown in a suitable nutrient medium without continuous shaking. The culture is kept undisturbed under controlled temperature conditions.

During bacterial growth, a thin layer of cellulose is formed on the surface of the liquid medium. After some time, this layer becomes thicker and forms a white gel-like sheet. This method is commonly used for laboratory production.

2. Agitated Cultivation Method

In this method, the bacterial culture is continuously mixed or shaken during the production process. This helps in better mixing of nutrients and oxygen in the medium.

However, the cellulose produced by this method may have a different shape and structure compared to the static method. In some cases, small cellulose particles or irregular masses are formed.

3.3 Preparation and Purification

After production, the bacterial cellulose is collected from the culture medium. It usually contains bacterial cells and other unwanted substances. Therefore, purification is necessary before using it for pharmaceutical purposes.

The general preparation steps include:

1. **Collection:** The cellulose layer is collected from the culture medium.
2. **Washing:** It is washed with water to remove the remaining culture medium.
3. **Purification:** The collected cellulose is treated with a suitable alkaline solution, commonly sodium hydroxide, to remove bacterial cells and impurities.
4. **Neutralization:** It is washed repeatedly with purified water until a neutral pH is obtained.
5. **Drying:** The purified bacterial cellulose can be dried or stored in its wet form, depending on its intended use.

3.4 Pharmaceutical Importance

Proper production and purification are important for obtaining good-quality bacterial cellulose. The final material can be used for preparing wound dressings, drug delivery systems and other biomedical products.

The production method and purification process can affect the structure, purity and quality of bacterial cellulose. Therefore, suitable conditions must be maintained to obtain material for pharmaceutical applications.

IV. BACTERIAL CELLULOSE AS A DRUG DELIVERY SYSTEM

Drug delivery systems play an important role in the treatment of different diseases and medical conditions. The main purpose of a drug delivery system is to deliver the medicine to the required site and release it in a suitable amount. In

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recent years, bacterial cellulose has gained attention as a material for drug delivery because of its special structure and water-holding capacity.

Bacterial cellulose contains a network of very fine fibres with small spaces between them. These spaces can hold different medicines and therapeutic substances. Due to this property, bacterial cellulose can be used as a carrier for antibiotics, antibacterial agents and other drugs.

4.1 Drug Loading into Bacterial Cellulose

Drug loading is the process of adding a medicine to bacterial cellulose. Different methods can be used for this purpose.

1. Absorption Method

In this method, bacterial cellulose is soaked in a solution containing the required drug. The drug enters the network structure of cellulose and gets absorbed into it. This method is simple and commonly used in laboratory studies.

2. Immersion Method

In this method, a bacterial cellulose membrane is placed in a drug solution for a particular period. The medicine gets distributed throughout the material. After that, the membrane is removed and used for further studies.

3. In-situ Loading Method

In this method, the drug or other active substance is added during the preparation of the bacterial cellulose material. This method can help distribute the drug within the cellulose structure.

4. Nanoparticle-Based Loading

In this method, drug-loaded nanoparticles are combined with bacterial cellulose. This approach may improve the delivery of medicines and provide better control over drug release.

4.2 Drug Release Mechanism

After loading the medicine, bacterial cellulose releases the drug when it comes in contact with wound fluid or moisture. The release of the drug depends on different factors, such as the type of drug, its concentration, the structure of cellulose and the surrounding conditions.

The main drug release mechanisms include:

1. **Diffusion:** The drug slowly moves from the cellulose network into the surrounding wound area.
2. **Swelling:** Bacterial cellulose absorbs water and swells, which helps the drug move out of the material.
3. **Degradation:** In specially designed cellulose-based systems, changes or breakdown of the material may help release the loaded drug.

4.3 Advantages in Drug Delivery

Bacterial cellulose offers several advantages as a drug delivery material:

- It can hold a good amount of water and medicines.
- It helps maintain moisture at the wound site.
- It can provide controlled drug release when properly designed.
- It can be combined with antibiotics and antibacterial substances.
- It is flexible and can be prepared in different shapes.
- It can be used for developing wound dressings and other medical materials.

4.4 Pharmaceutical Applications

Bacterial cellulose-based drug delivery systems are being studied for the treatment of burns, infected wounds, diabetic wounds and other skin injuries. Antibiotics and antibacterial agents can be incorporated into the material to help control bacterial growth.

Overall, bacterial cellulose is a promising material for developing new drug delivery systems. However, more research is needed to understand its drug release behaviour, safety and effectiveness in human patients.

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V. APPLICATIONS OF BACTERIAL CELLULOSE IN WOUND HEALING

Wound healing is an important process in which damaged skin and tissues are repaired. Proper wound care is necessary to prevent infection and support the formation of new skin. Bacterial cellulose has become an interesting material for wound treatment because of its ability to absorb water, maintain moisture and provide a suitable surface for cell growth.

Bacterial cellulose can be prepared in the form of thin sheets, membranes and hydrogels. These forms can be placed over wounds to protect the affected area and support the healing process.

5.1 Treatment of Burns

Burn injuries can damage the skin and increase the risk of infection. Bacterial cellulose-based wound dressings can help cover the damaged area and maintain moisture. They also act as a protective layer against external contamination.

These dressings can reduce direct contact between the wound and the surrounding environment. When combined with suitable antibacterial agents, they may also help control bacterial growth.

5.2 Treatment of Diabetic Wounds

Diabetic patients may develop wounds that take a long time to heal. High blood sugar levels and poor blood circulation can affect the normal healing process.

Bacterial cellulose-based dressings can help maintain a moist environment around diabetic wounds. They can also be combined with antibiotics and other active substances to support wound care. However, proper medical treatment is also necessary for diabetic wounds.

5.3 Treatment of Infected Wounds

Infected wounds are caused by the growth of harmful microorganisms such as bacteria. These infections can delay healing and may cause further tissue damage.

Bacterial cellulose can be combined with antibacterial substances such as silver nanoparticles and antibiotics. These combinations are being studied because they may help reduce bacterial growth and protect the wound from infection.

5.4 Treatment of Chronic Wounds

Chronic wounds are wounds that do not heal properly within the normal healing period. Examples include pressure ulcers, venous leg ulcers and long-lasting skin wounds.

Bacterial cellulose dressings can absorb wound fluid and help maintain suitable moisture levels. Their flexible structure also allows them to cover different wound shapes. These properties make them useful for developing new dressings for chronic wound management.

5.5 Role in Skin Regeneration

During wound healing, the formation of new skin cells is very important. Bacterial cellulose provides a network structure that may support the attachment and growth of skin cells.

Researchers are also studying bacterial cellulose combined with collagen, chitosan and other natural polymers. These combinations may improve its performance in wound healing and skin regeneration.

5.6 Benefits of Bacterial Cellulose in Wound Healing

The major benefits of bacterial cellulose-based wound dressings include:

1. Helps maintain moisture around the wound.
2. Absorbs excess wound fluid.
3. Provides a protective covering for damaged skin.
4. Can be combined with antibiotics and antibacterial agents.
5. Has good flexibility and strength.
6. Provides a suitable surface for cell growth.
7. Has potential applications in burn and chronic wound treatment.

Overall, bacterial cellulose has shown promising results in wound care research. However, further clinical studies are required to confirm its safety and effectiveness in different types of wounds.

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VI. ROLE OF BACTERIAL CELLULOSE IN TISSUE REGENERATION

Tissue regeneration is a natural process in which damaged tissues are repaired or replaced by new cells. It plays an important role in healing injuries and repairing damaged parts of the body. In recent years, bacterial cellulose has received attention in tissue engineering because of its unique structure and useful properties.

Bacterial cellulose has a fine network of fibres that can provide support for cell attachment and growth. It can also maintain moisture and provide a suitable environment for tissue repair. Due to these properties, researchers are studying its use in skin regeneration and other biomedical applications.

6.1 Skin Tissue Regeneration

Skin is the outer protective layer of the human body. When the skin is damaged due to burns, injuries or surgery, new skin cells are needed to repair the affected area.

Bacterial cellulose can be used as a supporting material for skin tissue repair. Its network structure provides a surface where skin cells may attach and grow. It can also be combined with collagen and other natural materials to improve its performance.

6.2 Cell Attachment and Growth

Cell attachment and growth are important steps in tissue regeneration. Bacterial cellulose provides a three-dimensional structure that may support the attachment and growth of different types of cells.

Its porous network allows water and nutrients to move through the material. This may help create suitable conditions for cell growth. However, pure bacterial cellulose does not provide all the biological signals needed for tissue development.

6.3 Bone Tissue Regeneration

Researchers are also studying the use of bacterial cellulose in bone tissue engineering. It can be combined with materials such as hydroxyapatite and calcium phosphate to improve its suitability for bone-related applications.

These combinations are being investigated for their ability to provide structural support and help in bone repair. However, more research is required before their routine use in patients.

6.4 Development of Tissue Engineering Scaffolds

A scaffold is a material that provides support for cells to attach, grow and form new tissue. Bacterial cellulose can be used to prepare scaffolds because of its strong fibre network and water-holding capacity.

These scaffolds can be modified by adding other polymers, proteins or nanoparticles. Such modifications may improve their mechanical strength and biological properties.

6.5 Combination with Other Natural Polymers

Bacterial cellulose can be combined with different natural polymers to improve its properties. Some commonly studied materials include:

1. **Chitosan:** It is a natural polymer that has been studied for its wound-healing and antibacterial properties.
2. **Collagen:** It is an important protein found in the skin and other body tissues. It helps support cell attachment and tissue repair.
3. **Gelatin:** It is a protein-based material that can improve the biological properties of cellulose-based scaffolds.
4. **Alginate:** It is a natural polymer that can absorb water and is used in wound dressing preparation.

These combinations are being studied for developing better materials for tissue repair and regeneration.

6.6 Importance in Biomedical Applications

Bacterial cellulose has potential applications in different areas of tissue engineering and biomedical research. Some of its possible applications include:

- Skin tissue repair.
- Burn wound treatment.
- Development of tissue engineering scaffolds.
- Development of artificial skin materials.
- Bone tissue engineering research.

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- Repair of damaged soft tissues.

Overall, bacterial cellulose is a promising material for tissue regeneration because of its special structure and ability to support cell growth. However, further research and clinical studies are needed to establish its long-term safety and effectiveness.

VI. RECENT ADVANCES IN BACTERIAL CELLULOSE-BASED DRUG DELIVERY SYSTEMS (2021–2026)

In recent years, bacterial cellulose has become an important topic in pharmaceutical and biomedical research. Researchers are trying to improve its properties by combining it with different drugs, nanoparticles and natural polymers. These combinations are mainly developed to improve wound healing, prevent infections and support tissue regeneration.

Some important recent developments are discussed below.

7.1 Antibiotic-Loaded Bacterial Cellulose

Researchers are studying the use of bacterial cellulose as a carrier for antibiotics. Antibiotics can be added to bacterial cellulose membranes to deliver the medicine directly to the wound area.

This approach may help control bacterial infections and provide local drug delivery. It can also reduce the need for frequent application of some topical medicines. However, its effectiveness depends on the type of antibiotic and the drug release properties of the material.

7.2 Silver Nanoparticle-Based Bacterial Cellulose

Silver nanoparticles have received considerable attention because of their antibacterial properties. Researchers have combined silver nanoparticles with bacterial cellulose to develop advanced wound dressings.

These materials are being studied for their ability to control bacterial growth and protect wounds from infection. They may also support the wound healing process. However, the amount of silver used must be carefully controlled because high concentrations may affect healthy cells.

7.3 Bacterial Cellulose and Chitosan Combinations

Chitosan is a natural polymer obtained from chitin. It is known for its potential antibacterial and wound-healing properties.

By combining chitosan with bacterial cellulose, researchers aim to develop wound dressings with improved biological properties. These combinations may help control bacterial growth and provide better conditions for wound repair.

7.4 Development of Bacterial Cellulose Hydrogels

Hydrogels are materials that can absorb and hold large amounts of water. Bacterial cellulose has a natural network structure that makes it suitable for hydrogel development.

These hydrogels can be used to carry medicines and release them slowly at the wound site. They also help maintain moisture, which is important for wound healing.

7.5 Plant Extract-Loaded Bacterial Cellulose

Natural plant extracts are also being studied for wound treatment. Extracts containing antioxidant and antibacterial compounds can be added to bacterial cellulose.

For example, Aloe vera, turmeric and other medicinal plant extracts are being investigated for their possible use in wound dressings. These combinations may help protect the wound and support tissue repair.

7.6 Bacterial Cellulose for Controlled Drug Release

One important development is the use of bacterial cellulose for controlled drug delivery. In this method, the medicine is released gradually from the cellulose material instead of being released all at once.

This approach may help maintain the drug concentration at the wound site for a longer period. It can be useful in developing advanced wound dressings for infected and chronic wounds.

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7.7 Use of 3D Printing Technology

Recent research has also explored the use of 3D printing technology in bacterial cellulose-based materials. This technology may help prepare wound dressings and tissue engineering structures in different shapes and sizes.

It may also help in developing materials according to the needs of individual patients. However, more research is required to improve the manufacturing process.

7.8 Recent Research Developments (2025–2026)

Recent review studies have focused on combining bacterial cellulose with antibiotics, metallic nanoparticles and other antibacterial materials. Researchers are also exploring its use in tissue engineering, skin repair and advanced drug delivery systems.

A 2025 review by Dang and colleagues discussed different methods of preparing antibacterial bacterial cellulose materials for wound dressing applications. Another review by Campano and colleagues in 2025 highlighted its growing importance in biomedical applications, including wound healing and tissue engineering.

In 2026, research has further focused on improving bacterial cellulose-based drug delivery materials and their use in advanced wound dressings.

Overall, these developments show that bacterial cellulose has good potential in modern pharmaceutical research. However, further studies are needed to improve its drug delivery performance and establish its safety and effectiveness in clinical use.

VIII. ADVANTAGES AND LIMITATIONS OF BACTERIAL CELLULOSE-BASED DRUG DELIVERY SYSTEMS

Bacterial cellulose is considered a useful material in pharmaceutical and biomedical applications because of its special properties. It is mainly used in research related to wound dressings, drug delivery and tissue regeneration. Like other materials, it also has some limitations that need to be considered.

8.1 Advantages

1. High Water Absorption:

Bacterial cellulose can absorb and hold a large amount of water. This helps maintain moisture around the wound and supports the healing process.

2. Biocompatibility:

It is generally compatible with the human body and can be used in contact with skin and tissues after proper preparation and testing.

3. High Purity:

Bacterial cellulose does not contain lignin and hemicellulose. Therefore, it has a relatively pure structure compared to plant cellulose.

4. Good Mechanical Strength:

It has good strength and flexibility, which makes it suitable for preparing wound dressings and medical membranes.

5. Drug Delivery Ability:

Its network structure allows different medicines, such as antibiotics and antibacterial agents, to be loaded into the material.

6. Moist Wound Environment:

It helps maintain a moist environment around the wound, which is important for proper wound healing.

7. Easy Modification:

Bacterial cellulose can be combined with other materials such as chitosan, collagen, silver nanoparticles and natural plant extracts to improve its properties.

8. Tissue Regeneration:

It can provide a supporting surface for cell attachment and growth. Therefore, it is being studied for skin repair and tissue engineering.

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8.2 Limitations

Although bacterial cellulose has many advantages, some limitations are also present.

1. High Production Cost:

The production of bacterial cellulose under controlled conditions can be expensive, especially when large quantities are required.

2. Slow Production Process:

The growth of bacteria and formation of cellulose may take several days. This can increase the time required for production.

3. Limited Drug Loading:

Pure bacterial cellulose does not always provide strong binding sites for different drugs. Therefore, some modification methods are required to improve drug loading.

4. Poor Biodegradability in the Human Body:

Bacterial cellulose is not easily broken down by enzymes present in the human body. This may limit its use in some applications.

5. Need for Proper Purification:

After production, bacterial cells and unwanted substances must be removed properly. Poor purification may affect the safety of the final product.

6. Limited Clinical Studies:

Many bacterial cellulose-based drug delivery systems are still under laboratory or preclinical investigation. More human studies are needed to confirm their safety and effectiveness.

7. Drug Release Problems:

The release of medicines from bacterial cellulose may depend on the drug type and preparation method. Sometimes, controlling the exact amount and speed of drug release can be difficult.

8.3 Overall Discussion

Bacterial cellulose has several useful properties that make it a promising material for pharmaceutical applications. It can be used in wound dressings, local drug delivery and tissue regeneration. However, problems related to production cost, biodegradability, drug loading and clinical testing need further attention.

With further research and development, bacterial cellulose may become an important material in advanced wound care and drug delivery systems.

IX. FUTURE PERSPECTIVES OF BACTERIAL CELLULOSE-BASED DRUG DELIVERY SYSTEMS

Bacterial cellulose has shown good potential in pharmaceutical and biomedical fields, especially in wound healing, drug delivery and tissue regeneration. Researchers are continuously working to improve its properties and develop new applications. In the future, bacterial cellulose may play an important role in advanced wound care and modern drug delivery systems.

Some important future possibilities are discussed below.

9.1 Development of Advanced Wound Dressings

In the future, bacterial cellulose may be used to develop advanced wound dressings for burns, diabetic wounds and chronic wounds. These dressings can be designed to maintain moisture, absorb wound fluid and protect the affected area from external contamination.

9.2 Smart Drug Delivery Systems

Researchers may develop smart bacterial cellulose-based drug delivery systems that release medicines according to the condition of the wound. For example, some systems may respond to changes in pH, temperature or other wound conditions. This could help provide more suitable treatment.

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9.3 Combination with Nanotechnology

Combining bacterial cellulose with nanoparticles may improve its antibacterial and drug delivery properties. Silver nanoparticles and other nanomaterials are being studied for their ability to control bacterial growth. These combinations may be useful in treating infected wounds.

9.4 Use of Natural Materials

In the future, bacterial cellulose may be combined with natural substances such as chitosan, collagen, gelatin and plant extracts. These combinations may improve its biological properties and support better wound healing.

9.5 Tissue Engineering Applications

Bacterial cellulose may have a greater role in tissue engineering. Researchers are studying its use in developing scaffolds that support cell attachment and growth. It may be useful in skin repair and other tissue regeneration applications.

9.6 Large-Scale Production

One of the main challenges is the high cost and time required for bacterial cellulose production. Future research may focus on using low-cost raw materials and improving bacterial growth conditions. This may help increase production and reduce manufacturing costs.

9.7 More Clinical Research

Although many laboratory studies have shown promising results, more clinical studies are required. These studies will help understand the safety, effectiveness and long-term performance of bacterial cellulose-based products in human patients.

Overall, bacterial cellulose has a promising future in pharmaceutical and biomedical research. With improvements in production methods, drug loading and clinical testing, it may become a useful material for advanced wound dressings and drug delivery systems.

X. CONCLUSION

Bacterial cellulose is a natural material that has gained importance in pharmaceutical and biomedical research. It has several useful properties, such as high water absorption, good mechanical strength, flexibility and biocompatibility. Due to these properties, it can be used in wound dressings, drug delivery systems and tissue regeneration.

Bacterial cellulose provides a suitable environment for wound healing by maintaining moisture and protecting the damaged area. It can also be combined with antibiotics, silver nanoparticles and other natural materials to improve its antibacterial and drug delivery properties. These combinations may help in the treatment of burns, diabetic wounds, infected wounds and chronic wounds.

Another important application of bacterial cellulose is tissue regeneration. Its network structure can support cell attachment and growth, which is useful for developing new materials for skin repair and tissue engineering.

Although bacterial cellulose has many advantages, some challenges remain, such as high production cost, limited drug loading, poor degradation inside the human body and the need for more clinical studies.

In conclusion, bacterial cellulose is a promising material for developing advanced drug delivery systems and wound dressings. Further research and clinical studies may help improve its applications in the pharmaceutical and medical.

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