Chapter 14

# Biopolymer Bacterial Cellulose Produced by Bacteria and its Use in Health

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**Abstract**

Bacterial cellulose is frequently used because it is economical and suitable for various production areas. Bacterial cellulose (BC) is a pure, crystalline material with superior properties, synthesized by aerobic bacteria. BC is produced by some bacteria, such as *Gluconacetobacter xylinum*, which stores abundant amounts of fibrils in 3D networks. Bacterial cellulose (BC) is a very comprehensive biomaterial. It is used in many areas such as the food industry, pharmaceutical industry, industrial and agricultural sectors. By producing bacterial cellulose from waste materials, it reduces costs and allows the use of environmentally friendly materials. BC can be used practically in different scientific researches and studies, especially in medical devices. Due to its excellent nanostructure and properties, bacterial cellulose is used in many medical treatments and textural applications. The search for new and active BC-producing microbial strains provides an impressive boost to BC production processes. Membrane types prepared with BC accelerate the wound healing process and prevent complications. Bacterial cellulose composites containing various materials have been designed to increase their applicability to living tissue. BC allows biocomposites to regulate cell adhesion for scaffolds and grafts. Bacterial cellulose, which is used to replace or support drug treatment, is increasingly being investigated. This study includes biocompatible and biodegradable bacterial celluloses, current biomedical applications, exploratory studies, and low cost BC production methods.

## 1. Introduction

Cellulose, one of the most important components of the primary cell wall of green plants, is a natural biopolymer that is quite common in nature (Updegraff, 1969). It forms the main structural component of the plant cell

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https://doi.org/10.58830/ozgur.pub305.c1286

wall and is frequently used in the production of paper, texturing and paper clay (Huber et al., 2012; Klemm et al., 2005, Gandini, 2008). The type of cellulose synthesized by tunicates, an ocean animal, is called astunisin (Zhao and Li, 2014). Regardless of the source, cellulose has the same chemical compositions but can differ in structure and have different physical properties (Brown, 1886; Ross et al., 1991).

Biocompatible natural biopolymers used in various materials and devices have become the preferred choice in research in medicine and related fields. Researchers' studies on the subject have led to the discovery of new systems, and this closely concerns the complex structures of tissue (De Oliveira Barud et al., 2016).

Cellulose (PC) formed by plants contains hemicellulose and lignin in its structure. Depending on the plant source used, the separation process may require toxic chemicals that are not environmentally friendly and have high costs (Vasconcelos et al., 2017).

Bacterial cellulose, which is a very promising material as well as a very pure natural exopolysaccharide, is produced by aerobic bacteria (*Gluconacetobacter, Agrobacterium, Aerobacter, Achromobacter, Azotobacter, Rhizobium, Sarcina and Salmonella*) (Jonas and Farah, 1998; Chawla et al., 2009). BC lacks lignin and hemicellulose and consists of microfibrils (Moniri et al., 2017 ). These microfibers will be arranged in a three-dimensional patterned structure that provides a porous geometry and high mechanical strength (Khan et al. 2015a; Mohite and Patil 2014). BC has high crystallinity (>80%) (Keshk, 2014), high water retention (Saibuatong and Phisalaphong, 2010) and degree of polymerization compared to plant cellulose varieties (Dahman, 2009). Due to these properties, it is used in biomedical and other related fields.

Nowadays, materials produced by tissue engineering are widely used in biomedical devices and products, wound & burn dressings, and treatment and healing of damaged tissues. Due to its excellent nanostructure and properties, microbial cellulose is a notable candidate for numerous medical and tissue engineering applications (Cherian et al., 2013).

Specially made materials that regulate environmental conditions and increase cell proliferation, growth, migration and modifications, thus increasing wound healing rates and allowing the wound closure process to occur more quickly, pave the way for the future of developing medicine (Lucchesi et al., 2008). The desired features of such devices are that the area where such devices are located is a humid environment, can be

absorbed from the blood, has important features such as gas exchange, heat permeability and minimum tissue adhesion (Boateng et al. 2008). Due to mediation, the interface plays a crucial role in wound healing, scaffolds (Nge et al., 2010), implants (Svensson et al., 2005), drug delivery systems and in vivo performance of biomaterials developed for medicine (Piatkowski et al., 2001; Martina et al., 2001).

BC medical applications werein skin repair treatments for burns, scars and ulcers. BC membranes have features such as speeding up the epithelialization process and preventing infections. Biocomposite materials prepared with Bacterial Cellulose have the capacity to significantly regulate cell adhesion in scaffolding and grafting processes, and very thin films of bacterial cellulose can be used in the application of diagnostic sensors that can be developed to neutralize many antigens (Picheth et al., 2017).

The aim of the chapter entitled "Biopolymer Bacterial Cellulose Produced By Bacteria And Its Use In Health" to focused on we have been explaining biomedical products that have been used in the health field up to now and may have potential for future use. Studies on BC have proven that it is a biomaterial that serves many areas. At the same time, its extraordinary molecular assemblies network structure and valuable properties in many biomedical applications have opened it to extensive international studies. Thanks to its natural and ultra-thin three-dimensional bacterial cellulose network structure with different properties, it can be used biomimetically in the production of materials similar to human and animal tissues. This study specifically aimed to expand the knowledge in this field and promote the practical application of BC and BC composites. From a scientific and material perspective, the most important task of these unique biopolymer cellulosic materials shows that extraordinary activities can be achieved using nanoscale materials.

## 2. Properties of The Bacterial Cellulose

The chemical structure of bacterial cellulose consists of chains of D-glucopyranose connected by β-1,4 glycosidic bonds (Picheth et al., 2017). Geometric state of the material; It is defined by forming parallel chains with hydrogen and van der Waals interactions between molecules. The structure containing large groups of molecules held together by intermolecular forces is called cellulose microfiber (Koizumi et al., 2008). Treatment of BC with sodium hydroxide creates an anti-parallel packing stabilized by a hydrogen bonding pack forming a significantly lower energy three-dimensional arrangement (Cellulose Type II) (Kolpak et al., 1978; Batenburg and Kroon., 1997).

Cellulose is an insoluble molecule with a molecular weight ranging from 2000 to 14,000. Studies on bacterial cellulose have shown that it is chemically similar to plant cellulose, but its macromolecular structure and characteristics are different from PC (Keshk and El-Kott., 2017).

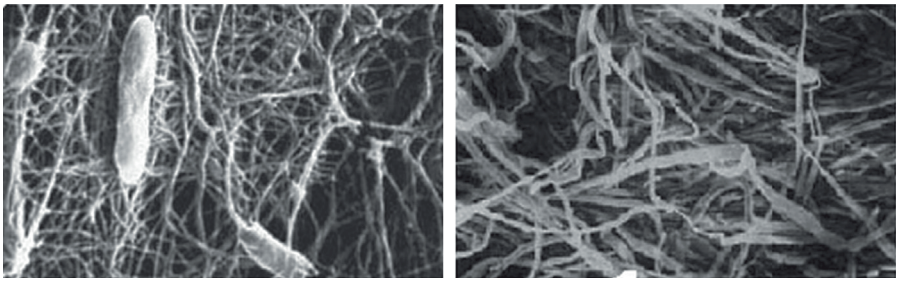

***Figure 1: Scanning electron micro images of bacterial cellulose(BC) and plant cellulose(PS) (Keshk and El-Kott., 2017).***

Bacterial cellulose is a natural biopolymer composed of glycosic units and mostly water, but its mechanical behavior is comparable to other synthetically produced artificial polymers and fibers, making bacterial cellulose as strong as synthetics. The tensile strength of BC is 200-300 MPa and the Young's modulus is 15-35 GPa (Ruka et al., 2014).

In general, the features of the BC research in the literature can be summarized as in the Figure 2.


***Figure 2: Properties of The Bacterial Cellulose***

The most important features that make bacterial cellulose superior are; It can be listed as providing mechanical strength even in moist state, showing biocompatible behavior, being non-toxic to living things, being environmentally friendly, having low density, and being biodegradable. When viewed from these perspectives, all these features make it suitable for all kinds of medical, tissue engineering, etc. making it a unique material in technological fields (Czajaet al., 2006; Hu et al., 2014; Klemm, et al., 2001; Svenssonet al., 2005; Shah, et al., 2013).

**3. Sythesis of Bacterial Cellulose**

BC was first published in 1886 by A.J. It was introduced by Brown from the extracellular cellulose synthase of the bacterium *Gluconacetobacterxylinus*. It has been found that the cell wall formed on the cellulosic surface during vinegar fermentation gives a chemically equivalent gelatinic matte structure (Keshk and El-Kott, 2017).

Bacterial cellulose production was characterized by Histrin and Shramm. HS developing the medium, HS medium; Made with glucose, peptone, yeast extract, disodium phosphate, citric acid and pH adjusted to 6. Variable nitrogen source, pH, and indicators affect the productivity of BC (Castro et al., 2015). Cellulose was then found to form on samples containing the cell-free extract of *Gluconacetobacter xylinus*, glucose and ATP, adhering to the traditional HS method. Starting from glucose, Gluconacetobacter xylinus produces cellulose in pellet form at the air/liquid interface of the culture medium in static culture (Hestrin and Schramm, 1954).

Many polysaccharide materials are secreted by gram-negative bacteria, but these bacteria are unable to produce more than a few types of cellulose. *Acetobacterxylinum* is a Gram-negative, aerobic, rod-shaped organism, but it has become the most studied BC source due to its ability to produce polymers at high levels and even under difficult conditions (Steinbüchel and Rhee, 2005, Ross, 1991).

Depending on the physiological state of the cell, bacteria that can produce gluconeogenesis and cellulose work together in the pentose-phosphate cycle or Krebs cycle (Ross et al. 1991). The glucose-cellulosic conversion mechanism, which includes cellulosic biosynthesis processes, occurs through *Acetobacterxylinum*. Bacterial cellulose synthesis is a precisely and specifically regulated multistep pathway involving large amounts of single and catalytic as well as regulatory protein clusters. Therefore, its supramolecular structure is not yet well defined (Bielecki et al., 2005).

Cellulose synthesis in microorganisms and plants consists of two steps; formation of the glucan chain by polymerization of glucose units; and synthesis and crystallization of the cellulose chain (Czaja, 2007). A schematic representation of this two-step pathway is shown in Figure 3 (Moniri et al., 2017). The cell forms BC between the outer and cytoplasmic membranes (De Ley et al., 1984). After the cellulose molecules are synthesized in bacteria, they are passed through the export components to form fibrils with an average diameter of 3 nm, and microfibers are assembled from these protofibrils in lines of approximately 80 nm (Iguchi et al., 2000).

Changes made in the culture medium of bacterial cellulose affect the productivity. Changes such as pH, nitrogen amount and carbon amount are the most important. *Komagataeibacter xylinum*, a most universally used strain, was grown in a liquid medium with many different carbon sources (e.g. amylose, maltose, rhamnose, glucose, etc.) (Ruka et al., 2014). If we think that glycerol is the main waste in biodiesel production, it may be economically attractive to reduce the cost with carbon stock. In addition, the authors encountered glucose as a carbon source and (Jung et al., 2010)

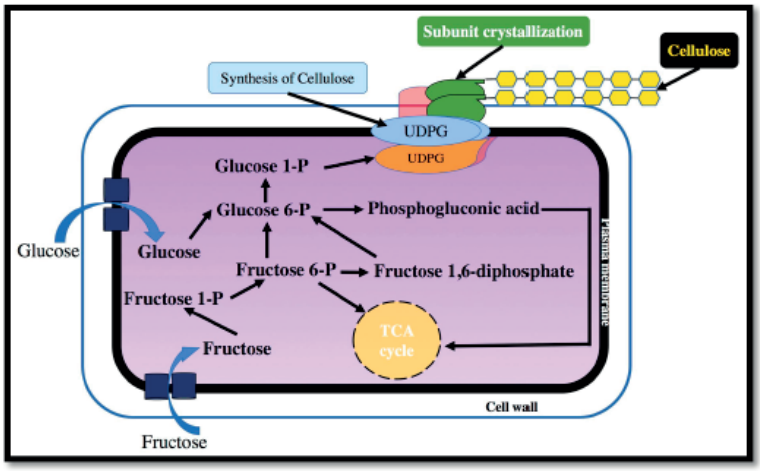


***Figure 3: Two-step biosynthetic pathway of cellulose in organism cells (Moniri et al., 2017)***

The production of biofuels and other chemicals with the structures formed as a result of the compact combination of cellulose, hemicelluloses and lignin is limited due to the inadequacy of enzymatic hydrolysis. Penttilä et al., (2018) used BC and wood-containing hemicellulose material in the composite material they used to examine the effect of enzymatic hydrolysis.

Hemicelluloses in particular found that BC synthesized in the presence of xylan was more sensitive than enzymatically hydrolyzed, hemicellulose-free bacterial cellulose. He reported that easier enzymatic hydrolysis is achieved with BC produced in this way and that it may offer new pursuits to come from the peak of biomass recovery through genetic engineering.

Additionally, various methods have been developed to obtain BC cost more economically. Islam and his colleagues applied these methods in their review studies; BC production from fruit juices (Kurosumi, 2009; Jagannath et al., 2014; Andrade et al., 2015; Hungund et al., 2013, Ha et al., 2011), sugarcane molasses (Bae and Shod, 2004), 2005; Keshk and Sameshima, 2006), agricultural and industrial wastes (Khan et al., 2015b; Shah et al., 2013; Hong and Qiu, 2008; Goelzer et al., 2009, Kuo et al., 2010; Shezad et al., 2009), reported as food waste (Khan et al., 2007; Wu and Liu, 2012; Tsouko et al., 2015).

BC production is basically carried out by two methods; It is a static and agitated method. Methods have different benefit and harm rates. While genetic stability is better in static culture, variants may occur in agitated culture. However, according to research, the physiological properties of BC produced by static culture were found to be more efficient compared to the properties of BC produced by agitated culture. (Deshpande et al., 2023).

### 3.1. Static Fermentation

A liquid-gas interface is used to produce BC via static fermentation. Microorganisms are added to the containers containing the medium and incubated for about 2 weeks under optimum conditions (28°C, pH: 4-7) until the desired film layer is formed. The resulting BC is then washed with sodium hydroxide and purified water until the desired pH value is reached (Sharma et al., 2021). In order for BC to reach its most efficient state, growth medium is added intermittently to the culture container. After BC reaches a certain size, growth stops due to depletion of resources such as nutrients in the environment.

### 3.2.Agitated Fermentation

The shaking culture method follows the same steps as the static method, but the shaking method uses an orbital shaking incubator. In static culture, as the amount of cellulose on the surface increases, oxygen transfers decreases. Therefore, sufficient oxygen cannot pass to the cultured bacteria. These limitations are eliminated because the shaking method provides sufficient oxygen and nutrients to the entire culture. With this method; The speed of

agitation and the nutrients provided are responsible for the efficiency of the BC. Figure 4 depicts the two main fermentation methods for BC synthesis (Deshpande et al.,2023).

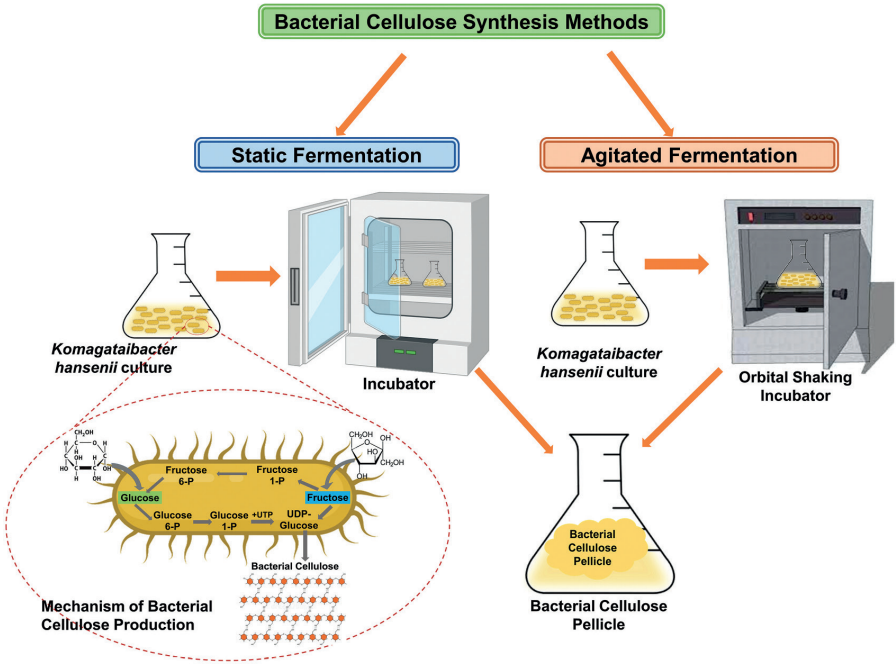


*Figure 4: BC Fermantation methods (Deshpande et al.,2023)*

## 4. Biomedical Application Areas of BC

BC is rapidly gaining great attention in the biomedical field because it is biocompatible, provides biodegradable properties, promotes cell epithelialization, is non-toxic, has the ability to trap moisture, has minimal tissue adhesion and has good pharmacological findings.

### 4.1. Wound Dressing

In an ideal wound dressing; It is expected to have properties such as ensuring gas exchange of substances such as oxygen, not causing infection or even preventing possible infections, keeping the area moist, not causing allergies to the person, providing epithelialization, absorbing exudates, and being able to separate from the surface without causing any irritation. So far, studies have been carried out on many types of biopolymers (chitin, chitosan, collagen, etc.) such as cellulose as wound dressings.

The most valid reasons for using bacterial cellulose as an artificial skin are; Features such as showing high mechanical properties in moist or wet state, providing the necessary permeability under optimum conditions, and minimizing irritation to the skin tissue can be given. (Choi S et al., 2022).

Almeida et al., (2014) in their study; They evaluated the potential irritation that BC may cause on human skin. By dividing BC patches into two types, with and without glycerin, they ensured that the types remained on the skin surface for 2 and 24 hours, and after the elapsed time, the patches were removed and measured trans epidermal water losses (TEWL). There was no significant difference in terms of the absence of barrier disruption after the measurements. They found similar results for erythema. The inclusion of glycerin in the study resulted in a reasonable skin moisturizing effect in the treatment of dryness-induced skin lesions such as dermatitis and psoriasis.

Studies have shown that bacterial cellulose can be used in the treatment of second and third degree burns and lesions in the skin tissue (Fontana et al., 1990). These studies have been tested on more than 300 patients and it has been documented that BC has many advantages during treatment, such as adhesion to the wound, decreased infection rate, ease of observation, and pain relief (Keshk and El-Kott, 2017). This has proven its feasibility both in terms of the patient's recovery time and in terms of economy. Biofill and gengiflex have used bacterial cellulose products in many areas such as the medical, dental and pharmaceutical sectors (Jonas and Farah, 1998).

In the study conducted on the resulting wound dressing (DermafillTM) product, it was observed that healing was achieved in a 75% shorter time with the use of bacterial cellulose.

One of the most famous bacterial cellulose composites used as wound dressings is the silver-containing BC-AG composite material. This is because the BC-Ag composite prevents the proliferation of bacteria without killing them and has bactericidal effects (Maneerung et al., 2008).

### 4.2. Artificial Blood Vessels

Artificial blood vessels are obtained especially with materials such as polyurethane and DACRON. BC has opened a new path in tissue engineering with its excellent mechanical properties for obtaining artificial blood vessels (Choi S et al., 2022). BC can replace arteriosclerotic vessels, is sufficient for use, has mechanical properties close to small diameter (<5) vessels (Klemm et al., 2001), has high burst pressure, has good water retention, has a pure fibrous structure and is environmentally friendly. It is a suitable biopolymer for artificial blood vessels because it does not damage tissues.

Another idea put forward by Fink (2009) is; reported that bacterial cellulose may pose less risk of blood clotting than other synthetic types. This means that BC is an ideal material for artificial blood vessels. When real blood vessels are examined, they are seen to have an inner cell that enables blood clotting.

Studies have shown that the carotid artery was successfully implanted in animal experiments and that the developed material and stability has shown that it is preserved for a long time (Schumann et al., 2009).

Zang et al., (2015) produced artificial blood vessels from bacterial cellulose using *Gluconacetobacter xylinum*. The artificial blood vessels created were shaped like tubes. It was determined that there was no toxic effect on the cells cultured in BC tubes and the surrounding tissues. BC tubes, which proved their effectiveness in vitro, were later implanted into New Zealand rabbits (Figure 5), and complete endothelialization was observed in the in vivo study (Choi S et al., 2022).

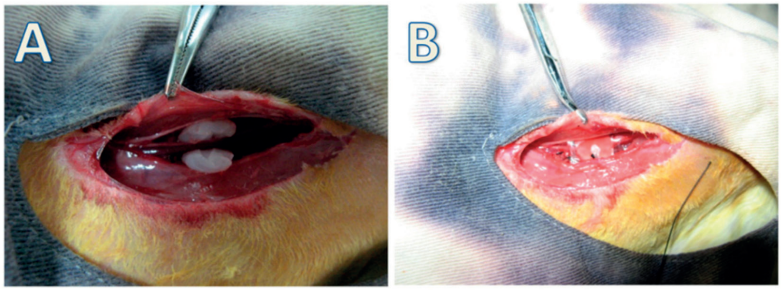


***Figure 5: BC graft implanted in rabbit (Choi S et al., 2022)***

### 4.3. Bone and Cartilage Tissue Engineering

Bone disease can be difficult to heal and can lead to major tissue disorders that require bone grafts to support the healing process. It may be possible to treat the bone loss by replacing it with material that is transplanted from another human or another species as an alternative (Palsson and Bhatia, 2004; Deng and Liu, 2005).

To find an alternative method of bone structure in the living body, many researchers have worked on biomaterials that mimic bone. Bone tissue in general; It consists of collagen and calcium hydroxyapatite. Studies have shown that bacterial cellulose and hydroxyapatite can form scaffolds by combining them in harmony (Choi S et al., 2022).

The BC scaffold obtained from *Acetobacter xylinum* X-2 loaded with BMP-2 was found to have a suitable ossification feature in fibroblast cells of mice in in vitro studies. In a mouse study of BMP-2 coated BC scaffold, it was observed that bone formation increased and calcium reached high levels within 4 weeks after implantation (Shi Q. et al.,2012).

In another study, Codreanu et al., (2020) developed scaffolds for rats using BC-modified polyhydroxyalkanoates, salt and tributyl citrate. When the modified BC scaffold was examined 4 weeks after implantation, osteoblast differentiation was observed. When examined again after 20 weeks, more ossification was observed (Figure 6).

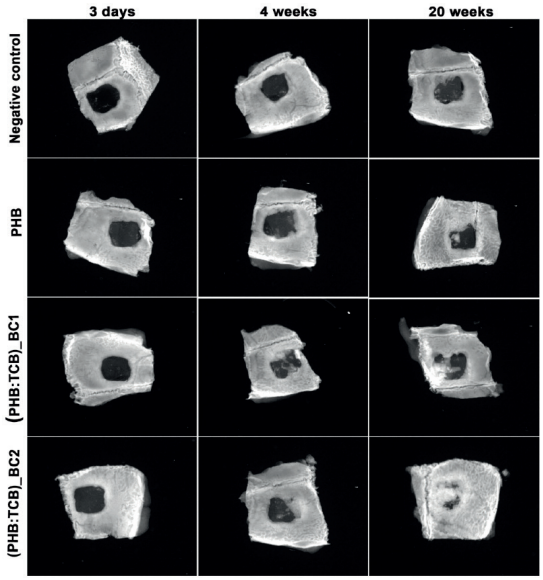


***Figure 6: Bone treated with scaffolds (Codreanu et al., 2020)***

Since articular cartilage is not a tissue that can fully renew itself, a lot of research is being done to repair the cartilage. Studies have been developed specifically on a structure in which the biomaterial can bind to chondrocytes and proliferate. It has been seen in studies that bacterial cellulose obtained from bacteria contributes to the proliferation of chondrocytes (Svensson, 2005). In the same study, it was observed that unmodified BC showed higher efficiency than its modified form. For these reasons, it has been determined that bacterial cellulose is a suitable scaffold model for cartilage repair (Choi S et al., 2022).

In another study, nanofibers consisting of bacterial cellulose (<1%) containing PVA nanocomposites were prepared and subjected to thermal cycling to examine their mechanical properties. PVA-BC nanocomposites have been investigated as potential materials for articular cartilage, and PVA-BC nanocomposites have tunable elastic modulus sizes similar to that of original articular cartilage. showed compressible mechanical properties (Millon et al., 2009).

### 4.4. Artificial Cornea and Retina

The cornea is a curved and curved tissue that is specialized to protect the eye's vision and protect it from external factors. Problems occurring in the cornea are an important cause of vision loss. It is a technique that replaces damaged corneas with keratoplasty to reverse vision loss (Foster, 2003; Whitcher et al., 2001). Techniques developed in the field of tissue and bioengineering are applied to provide cornea-like tissue, and these techniques make artificial cornea synthesis possible (Ullah et al., 2016). In this context, BC has pioneered the discovery of this remarkable material with light transmittance and biocompatibility as an innovative scaffold (Hui et al., 2009 ).It has been shown that corneal stromal cells can be maintained, replicated and reproduced in BC scaffold. It is argued that BC stands support inward growth of corneal stromal cells, which suggests that the potential for engineering corneal production. (BC-PVA-nHA) composite (Kharaghani et al., 2015) showed that the water content (82-84%) of BC-PVA-nHA composites resembles almost natural human cornea (78%).

Various BC biocomposites have been described to fully adapt the properties of the material used for eye treatment. For example, Wang et al., (2010) increased the light transmittance and UV absorption of BC by adding polyvinyl alcohol to BC; Goncalves et al., (2015) have reported that they show an RPE proliferation using improved chitosan and carboxymethyl cellulose by increasing the hydrophilicity of BC by surface modification. In addition, different functional structures have been reported to produce three-dimensional structures that are more suitable for cell growth to relieve artificial cornea or glaucoma (Chiaoprakobkij et al., 2011; Zaborowska et al., 2010). Therefore, many BC composites can support the development of corneal stromal cells while preserving the person's vision. Materials such as poly(methyl)methacrylate and hydroxyapatite, which are available in clinics and have a higher probability of irritation compared to BC composites, are expected to be replaced by BC in terms of their use as eye scaffolds (Dutton 1991).

### 4.5. Dental Implant Material

Compatibility of dental implants used in dental health with the surrounding tissue is a challenging problem. Osseointegration is especially necessary between the dental bone tissue and the implant. The high mechanical properties of bacterial cellulose, its compatibility with the surrounding tissue, its ability to not lose its properties under wet conditions and its absorption capacity are proof that it can be used in dental health applications (Choi S et al., 2022).

Yoshino et al. (2013) evaluated the use of BC as a root canal treatment material for intradental abscess formation. In this study; Cellulose strains were prepared using BC membranes produced by *Acetobacter hansenii* (ATCC 700178 and ATCC 35059). The mechanical properties and drug release efficiency of BC were found to be higher under simulated conditions, thus indicating that bacterial cellulose has high potential for root canal treatments.

Olyveira et al., (2014) reported that the use of BC as dental biometry produced significant results. In addition, biomimetic precipitation of calcium phosphate, a biological concern on bacterial cellulose, has been studied by mimicking body fluids. Chondroitin sulfate activity in bacterial cellulose was analyzed by characterization studies and confirmed that calcium phosphate participates in the uniform spherical form of bacterial cellulose nanocomposite surface and calcium phosphate particles. They point out that future work will lead the cell adhesion and vitality feature.

### 4.6. Drug Delivery Systems

In recent years, chitosan, alginate, cellulose, etc. have been used for drug delivery systems. A lot of biomaterial research has been carried out including natural biopolymers. Especially biomaterials containing BC; It is frequently used in drug delivery system applications due to its high pore size, non-toxicity to living beings, fine structure and biodegradability. Drug delivery materials prepared using BC; It can provide drug release in a controlled manner through impregnation by providing thin film layers.

Amin et al., (2012) carried out studies to determine the usage areas of BC in drug delivery systems, hydrogel syntheses and drug applications. First, for the production of hydrogels, BC was exposed to electron beam at different rates and then acrylic acid (AA) was added. Characterization analysis determined that AA was successfully impregnated onto cellulose fibers and the reaction mechanism in hydrogel synthesis was predictable. Other analyzes showed the formation of thermally stable hydrogels with AA

content and the pore size determined by the irradiation dosage. The results of swelling and in vitro drug release studies revealed that hydrogels are both thermo and pH sensitive. In addition to the morphological properties of these thermo and pH responses, these BC / AA hydrogels are promising for future use of controlled drug delivery systems.

Silva et al., (2014) investigated the roles of BC membranes in the transdermal drug delivery system for anti-inflammatory drug. Bacterial cellulose films loaded with diclofenac sodium salt as anti-inflammatory were prepared using plasticizer (glycerol) and characterization tests were performed for its morphology. In vitro studies performed with Franz cells showed that the incorporation of diclofenac into bacterial cellulose membranes provided penetration rates similar to those achieved with other commercially available membranes. This widespread profile facilitates the incorporation of drug loading membranes to ensure ease of administration and excellent potential for the use of membranes for transdermal delivery of diclofenac.

### 4.7. Other Researchs

Evans et al., (2003) BC contrary to plant cellulose, it is beneficial to catalyze the accumulation of metals to form a finely disunited homogeneous catalyst lamina. Empirical data in the literature have shown that BC, aqueous solution of palladium, reducing groups has the capacity of initializing gold and silver precipitation. In the research conducted by Evans et al., (2003) BC was dehydrated to a thin membrane texture acceptable for the construction of membrane electrode assemblies (MEAs), since it contained water equivalent to at least 200 times the dry weight of cellulose. The results of working with palladium-cellulose have shown that when incubated with sodium dithionite, they can catalyze the formation of hydrogen and form an electric current from the hydrogen in an MEA containing a natural cellulose as a polyelectrolyte membrane (PEM). The advantages of using natural and metallized bacterial cellulose membranes in an MEA compared to other PEMs such as Nafion 117® are reported to be the higher thermal stability of the gas passage at 130 °C and lower. Gadim et al., (2016) described the characterization of a Nafion® / bacterial cellulose (BC) nanocomposite prepared by impregnating a nanofibrillar BC membrane with Nafion®. Such a nanocomposite membrane is crack-free and has a thickness close to 100 $\mu$m and has been shown to be applied in an air / hydrogen fuel cell membrane Nafion® / BC membrane.

Meniscus lesions due to alternating cell damage after a trauma or in the absence of any trauma, damage or tumor are a frequently seen problem in

society. Once the meniscus is removed, it cannot regenerate. Lesions grow and cause osteoarthritis. Collagen meniscus implants have been used in clinical applications to structure the meniscus tissue and provide function. Bodin et al., (2007) matched the properties of BC with porcine meniscus using a collagen material. The collagen meniscus implants were used in clinical practice to reconstruct the meniscus tissue after partial meniscectomy. the swine meniscus is clearly stronger in the higher compaction strain due to the regular and ordered structure of the collagen fibrils in the meniscus. BC can be produced as a meniscus that is cheap and easy to combine and promotes cell migration, making it an attractive material for meniscus implants.

Silver has been the most commonly exploited and used inorganic metal against infections since antiquity. Several ways in which silver ions kill bacteria have been mentioned in the literature as follows. First is the interaction of silver ions with thiol groups of enzymes and proteins important for bacterial respiration and cell wall and transport of the parent substance in the cell. and the binding of silver ions to the bacterial cell membrane and the outer bacterial cell by altering the function of the bacterial cell wall (Cho et al., 2005; Sondi et al., 2004; Percival et al., 2005). The silver metal is converted into silver ions slightly with the physiological system and interacts with the bacterial cells. Knowledge exists that silver nanoparticles with effective antibacterial, antifungal and antiviral properties are attractive antibacterial agents (Rai et al., 2009). Maneerung et al., (2008) used silver nanoparticles to create BC antimicrobial activity. The findings indicate that freeze-dried silver nanoparticle-impregnated BC is important for gram-negative and (*Escherichia coli*) gram-positive (*Staphylococcus aurous*) bactericides.

Acasigua et al., (2014), they modified the bacterial cellulose fermentation process by adding hyaluronic acid and gelatin (1% w / w) before the bacteria were inoculated. Characterization of bacterial celluloses affected by hyaluronic acid and gelatin was analyzed and adhesion and viability studies were performed with human female pulp stem cells using natural bacterial cellulose / hyaluronic acid as a skeleton for regenerative medicine. MTT viability assays have reported higher cell adhesion over time in bacterial cellulose / gelatin and bacterial cellulose / hyaluronic acid scaffolds with differences in fiber agglomeration in bacterial cellulose / gelatin. Thus, the use of bacterial cellulose in stem cell cells has been reported for the first time in this study.

There are a number of studies that have been in use and continue to be investigated. These studies are shown in Table1.

***Table 1. Application areas of BC composites***

| Biomedical and Pharmaceutical Applications of BC-Based Composites | |
|---|---|
| Artifical Blood Vessels | Contact Lenses |
| Bionalysis | Transdermal Patches |
| Meniscus Implants | Biosensors |
| Cardiovascular Tissue Replacement | Bone Tissue Regeneration |
| Artifical Endocranium | Anti- viral Film |
| Hemodialysis | Vertabral Disc Replacement |
| Drug Delivery and Enantiomer Separation | Ligaments and Tendons Substitues |
| Stem Cell Teraphy | Anti-microbial Wound Dressing |
| İmmobilization of Enzymes and Cells | Dental Root Canal Treatment |
| Tissue Engineering of Cartilage | Artifical Cornea |

## Conclusion

Bacterial cellulose is a naturally occurring, renewable polymer with a wide range of uses. This type of polymer is obtained from the bacterium *Gluconacetobacter xylinus*. BC; It is a polymer that does not contain lignin and hemicellulose and has high mechanical properties, purity, crystallinity and an unchanging structure. Unique properties such as high water retention capacity and good chemical stability make BC unique. BC can be produced in almost any shape due to its high malleability. BC is a truly interesting, emerging biomaterial that has proven to be useful in various aspects in biomedical application. BC has a structural appearance that is far superior to plant cellulose.

In this article review, BC and BC composite materials were examined in general and the use of BC-related nanocomposites such as collagen, gelatin, fibroin, chitosan, silver, alginate, hydroxyapatite, BC nanocomposites were examined along with the examined materials. Therefore, this paper revisited and presented a number of different BC and BC composite materials designed for biomedical applications (wound dressings, cell scaffolds, drug delivery systems), among other descriptions. Based on this, we concluded that BC composites have many unique properties such as strength in their mechanical structure, high water retention capacity, in vitro and in vivo biocompatibility, and biodegradability. These include different composite BC membranes, wound dressings, dental prosthetics, skeletal and cartilage implants, and especially in biomedical fields such as drug administration.

BC exhibits excellent material properties alone or in composite form and can therefore be used as drug carriers, especially in topical and transdermal delivery systems. We also hope that this chapter can be shortened to bring together high-quality information from the literature to inspire the development of new materials on bacterial cellulose.

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