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Study on Chitosan Composite Biomaterials Based on Nano-Carbon Materials

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Abstract: Nanofiber reinforced composites have attracted wide attention in the field of biomaterials because of their unique structural advantages. Chitosan has good biocompatibility, hemostatic and antibacterial properties, and has a wide application prospect in the field of biomaterials. However, the poor mechanical properties of chitosan limit its application. Silk micro-nano fibrils have good biocompatibility, degradability in vivo and excellent mechanical properties. If different forms of polysaccharide-protein composite biomaterials can be obtained based on chitosan and silk fibroin nanofibers, its application in biomedical engineering materials will be expanded.

1. Introduction

Chitosan is a kind of aminopolysaccharide widely existing in nature, and it is the product of chitin after deacetylation. Chitin is a kind of natural high molecular compound, which is rich in sources and widely exists in the shells of lower animals such as arthropods (shrimps, crabs, etc.), mollusks (turtles, shellfish, oysters, etc.), annelids (earthworms, grasshoppers, horned nest worms, etc.), and the cell walls of lower plants, bacteria and algae. It is a natural polymer second only to cellulose in yield and importance [1].

It is estimated that the amount of chitosan biosynthesis in the world is nearly 100 billion tons every year, which is extremely rich in resources. If we can make full use of these chitosan resources, it will be of great significance to waste biodegradation, energy saving and emission reduction, environmental protection and sustainable development. Although the yield of chitosan is abundant and easy to obtain, the utilization rate of chitosan is still very low up to now. The main reasons are that the processing performance of chitosan material is very poor, it cannot be melted by heating, and it is easy to lose water and carbonize. Pure chitosan materials can not be molded by traditional molding methods of polymer materials, such as melt extrusion and injection molding.

2. Overview of Chitosan

2.1 The Basic Structure of Chitosan

Chitosan is composed of carbon, hydrogen, oxygen and nitrogen, and its basic structural units are 2- acetamido -2- deoxy -β-D- glucopyranose and 2- amino -2- deoxy -β-D-glucopyranose which are connected by 1-4, which are a binary linear copolymer [2].

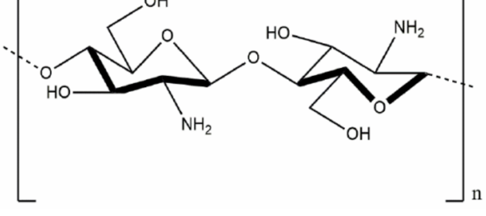

Fig.1 Chemical Structural Formula of Chitosan

Chitosan is the only cationic alkaline polysaccharide in nature, and its macromolecule is rich in amino, carboxyl and acetyl groups. The existence of amino group endows chitosan with a certain degree of alkalinity, and amino group has high reactivity, which can make chitosan undergo various chemical reactions, such as grafting reaction, metal chelating reaction, quaternization reaction, alkylation reaction and so on [3]. Acetylamino groups in chitosan molecules can also have corresponding reactions under specific conditions, and carboxyl groups can have chemical reactions such as etherification and esterification.

2.2 Basic Properties of Chitosan

Chitosan can be dissolved in inorganic acids, such as dilute hydrochloric acid and dilute nitric acid, but insoluble in sulfuric acid and phosphoric acid. Chitosan can also be dissolved in organic acids, such as formic acid, acetic acid, oxalic acid and lactic acid. The essential reason for the dissolution of chitosan in dilute acid is the electrostatic repulsion between macromolecular chains. The molecular chain of chitosan is rich in hydrophilic groups[4]. However, due to intramolecular and intermolecular hydrogen bonds in its structure, chitosan with high molecular weight cannot be directly dissolved in water. However, there are abundant amino groups (-NH2) in the molecular chain of chitosan, which can combine with free hydrogen ions (H+) in the solution to produce protonation, and then transform chitosan macromolecule into positively charged polycations. The intramolecular and intermolecular hydrogen bonds are broken by electrostatic repulsion, thus completing the dissolution process of chitosan. The solution formed by dissolving chitosan in acidic solution system has certain instability. The glycosidic bond in chitosan is a hemiacetal structure, which is unstable to acid. Therefore, the acid-catalyzed hydrolysis reaction gradually occurs in the acidic solution of chitosan, and the molecular weight and solution viscosity are reduced due to the breakage of the macromolecular main chain.

Chitosan is a polyelectrolyte. In acidic solution, amino groups in its main chain combine with protons and then protonate. Amino groups with positive charges can interact electrostatically with electrolytes or polyelectrolytes with opposite charges. The protonation process of chitosan is closely related to macromolecular structure, and is influenced by factors such as deacetylation degree, amino distribution, molecular weight and molecular conformation.

Chitosan has natural antibacterial property and can inhibit the growth of various bacteria and fungi. Its antibacterial property is closely related to molecular weight and degree of deacetylation. At present, the mechanism of antibacterial property of chitosan is that the positively charged amino group in the macromolecular chain of chitosan can combine with phospholipid membrane in bacterial cell membrane through electrostatic action to produce chemical reaction, thus destroying the growth and development of bacteria, inhibiting the exchange of substances between bacteria and the outside world, and finally leading to the extinction of bacteria [5].

In addition, chitosan molecules contain a large number of hydroxyl (-OH) groups and amino (-NH-) groups, which can chelate metal ions with a certain ionic radius under certain P H conditions. The molecular chain has more active hydroxyl and amino groups, which can chemically react with various substances. Other groups and side chains are introduced to change the original chemical and biological properties of chitosan, and new materials with novel structure and enhanced functionality are obtained, thus further expanding the application of chitosan.

2.3 Application of Chitosan Membrane in Biomaterials

Chitosan has excellent film-forming ability and is widely used in biomaterials. Chitosan membrane has good antibacterial and hemostatic properties, can improve the wound healing rate, and is a good wound repair material. At the same time, chitosan membrane can also be used as the carrier of bioactive drugs, which can be loaded from small molecules such as antibiotics to large molecules such as protein.

The basic raw material of Hemcon Strip Pro medical bandage is chitosan dissolved in acetic acid, which is dried by infrared ray or oven to obtain chitosan film. Chitosan-based bandage material is selective to CO2, O2 and other gases, and has high permeability to water vapor, which has a good wound repair effect [6].

Tang et al. prepared ibuprofen-loaded chitosan membrane by supercritical solution impregnation method, and studied its oral mucosal drug delivery. In vivo experiments confirmed that 70% of the drugs were released from the matrix within 460 min, and the supercritical impregnation method had many advantages such as low solvent residue and controlled and sustained release. Varshosaz et al. studied the release behavior of lidocaine (LC) on chitosan films. In this study, chitosan/lidocaine composite films were prepared by crosslinking sodium tripolyphosphate (TPP), and the drug release rates of lidocaine on three chitosan films with different molecular weights and concentrations were compared. It was found that with the increase of chitosan concentration and molecular weight, the drug release rate and degree increased. However, with the increase of cross-linking agent (TPP), the drug release rate and degree decreased. The results of this study have good clinical guiding significance.

2.4 Application of Chitosan Scaffold in Biomaterials

Chitosan has good biocompatibility, which can be used not only as a membrane material for wound repair, but also as an implantable material such as tissue engineering scaffolds. Researchers are constantly exploring the potential of chitosan scaffolds as biomaterials, so as to eliminate the limitations of existing materials in structure and performance, and achieve most of the ideal performance of scaffolds. It will be an important subject in the research field of chitosan biomaterials to modify chitosan or blend it with other polymers to prepare scaffold materials with better performance [7].

Chitosan is a scaffold material with three-dimensional porous structure, and it is a good biological matrix carrier. Many researchers have devoted themselves to the study of chitosan scaffold materials loaded with various growth factors. Nandi et al. studied the effectiveness of chitosan porous scaffold and its combination with insulin growth factor -1 and bone protein (BMP)-2 in repairing rabbit tibia defect. The research shows that chitosan scaffold material combined with growth factors can be successfully used for bone defect healing. On the other hand, the mechanical properties of chitosan scaffold materials are poor, which can be eliminated by adding other biomaterials. Hydroxyapatite is a good reinforcing material, which can be used to make up for the weakness of chitosan scaffold. The effect of nano-fiber hydroxyapatite chitosan composite on bone regeneration in the process of bone marrow mesenchymal stem cells (BMSCs) cultivation and its potential mechanism in vivo and in vitro indicate that compared with composite membrane and composite filament material, the composite scaffold material with three-dimensional size has a more positive effect on inducing the proliferation of bone marrow mesenchymal stem cells. Guo et al [8]. prepared nano hydroxyapatite-chitosan composite scaffold with good mechanical strength and elastic modulus. The scaffold supports proliferation and adhesion of BMSCs cells. It can also significantly improve osteogenesis ability and has good biological properties.

2.5 Application of Chitosan Fiber in Biomaterials

Chitosan fibers prepared by wet spinning also have great application prospects in the field of biomaterials. Chitosan fiber can be prepared by dry-wet spinning process with glacial acetic acid solution as raw material and lithium chloride /N, N- dimethylacetamide as solvent. However, the mechanical properties of pure chitosan fiber are deficient. Chitosan can be blended with other materials such as sodium alginate, procollagen, cellulose, sodium hyaluronate, sodium heparin, sodium chondroitin sulfate and polyacrylic acid to prepare composite fibers to improve the properties of pure chitosan fibers, which can be used to produce high-performance fibers with low cost and high benefit. Dobrovol'skaya et al. added chrysotile nanotubes to chitosan, and the chitosan fiber produced by wet spinning process had good orientation, which enhanced the strength and Young's modulus of the fiber. However, chrysotile was not biodegradable, which limited its application in biomaterials. Yudin et al. used 2% acetic acid aqueous solution as raw material to prepare composite chitosan fiber filled with chitin nanofiber by wet spinning process. The research found that the introduction of chitin nanofiber into chitosan matrix is helpful to increase the orientation of chitosan macromolecule, thus improving the strength and Young's modulus of chitosan/chitin composite fiber. At the same time, chitin is degradable and can be used in tissue engineering and other fields.

3. Overview of Natural Silk Nanofibres

3.1 Structure and Properties of Silk Fibroin

Silk protein is a kind of natural polymer material, and it is also the earliest protein material used by people on a large scale. It is secreted by silk glands in the body when mature silkworms cocoon. As shown in Figure 2, silk is mainly composed of silk fibroin and sericin, in which silk fibroin inside silk accounts for 70-75% of the fiber [9], while sericin outside silk fibroin accounts for 25-30%. When sericin is used as biomaterial, because sericin is easy to cause immune rejection in vivo, measures are usually taken to remove sericin on the surface of silk fiber, leaving only the silk fibroin inside. Silk fibroin is mainly composed of polypeptide chains with different molecular weights (heavy chain: 350kDa and light chain: 25kDa), and the chains are mainly connected with each other by disulfide bonds. There are two main crystalline structures of silk fibroin: silk ⅰ and silk ⅱ, among which silk ⅰ is a metastable structure and silk ⅱ is a stable crystalline structure. Under some conditions, silk fibroin can undergo the structural transformation from metastable state (silk ⅰ) to stable state (silk ⅱ).

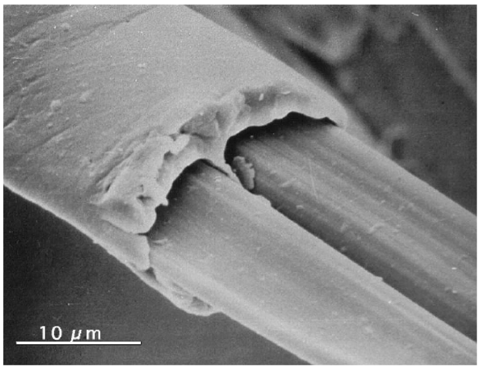

Fig.2 Sem Picture of Silk Fiber

3.2 Basic Properties of Natural Silk Fibroin Nanofibers

Silk fibroin fibers are assembled from smaller-scale silk fibroin nanofibers (as shown in Figure 3). Compared with the “bottom-up” silk fibroin nanofiber manufacturing method, silk fibroin fiber is dissolved first to obtain silk fibroin solution, and then regenerated silk fibroin nanofiber is prepared; The natural silk fibroin nanofibrils prepared by the “top-down” method are directly prepared from natural silk fibroin fibers. This preparation method has greatly retained the originality of silk fibroin fibers, especially the excellent mechanical properties of nanofibrils and the aggregation structure of silk fibroin molecular chains. Therefore, natural silk fibroin nanofibrils can be incorporated into films, coagulated limbs or scaffolds to form composite materials, which can give full play to the mechanical enhancement of nanofibrils, improve the mechanical properties of materials, and make full use of the good biocompatibility of silk fibroin [10].

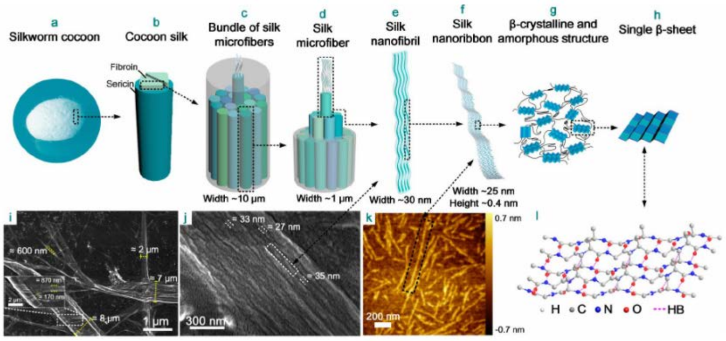

Fig.3 Hierarchical Structure of Silk Fibroin Fiber

4. Conclusions

As a new type of high-performance material with ultra-high specific surface area, nanofibers are widely used in various fields such as environmental treatment, biomedicine, engineering materials and so on. As a natural polymer, silk fibroin has many advantages, such as wide sources, easy access, excellent mechanical properties, biodegradability and so on, and has great application potential in nanofiber materials. Natural silk has complex structure and high crystallinity, so it is a great challenge to extract nanofibres directly from natural silk. Based on the previous research of the research group, mild chemical methods were used to treat degummed silk fibroin fibers to release the force between fibrils. Messy fibrous, three-dimensional network-like structure. Through XRD, SEM, TEM and XPS tests, we know that chitosan first forms granular substances on the surface of conductive stainless steel sheet. With the prolongation of electroplating time, chitosan crystals complexed with calcium ions grow gradually. At this time, chitosan-calcium carbonate structures at the crystallization sites grow faster than those at other positions, and gradually form fibrous structures. Because of the complexability of calcium ions, chitosan-calcium carbonate fibers are gradually connected with each other and finally form a three-dimensional network structure.

References

[1] Zhang Yongxiang, Liao Jianguo, Li Yanqun, et al. Research on nano hydroxyapatite / chitosan composite biomaterials [J]. Materials guide, 2017, 31 (017): 53-60.

[2] Tao Han, Zhang Yiming, Han Li. Electrochemical immunosensor based on ionic liquid / nano materials and methylene blue composite membrane [J]. New chemical materials, 2013, 41 (9): 96-98.

[3] Yang Wen, Luo Mingdeng, Hao Wentao, et al. Research progress on the construction and application of biosensors based on chitosan gold nanoparticles [J]. Materials guide, 2008 (12): 80-82 + 96.

[4] Wang Beibei, Ji Xueping, Li xianrui, et al. Study on glucose biosensor based on nanocomposite / chitosan membrane [J]. Analysis laboratory, 2013, 32 (6): 20-23.

[5] Zhao Hongye, Qiao Liyun, Wei Junping. Application of electrochemical biosensor based on electrodeposited calcium carbonate chitosan composite nano materials [J]. Progress in analytical chemistry, 2012, 2 (3): 5.

[6] Shi Chuan, Yang Lan, Cao Youzhen, et al. Research progress of graphene / chitosan electrochemical biosensor [J]. New chemical materials, 2017, 045 (007): 1-3.

[7] Liu Yan, Niu Weifen. Development of H2O2 biosensor based on graphene chitosan horseradish peroxidase [J]. Analytical laboratory, 2012, 031 (008): 79-82.

[8] Peng Huaping, Cha Daijun, Huang Zhengjun, et al. Study on Ferrocene functionalized Fe3O4 / carbon nanotube / chitosan composite membrane glucose biosensor electrode [J]. Electrochemistry, 2014, 20 (1): 33-33.

[9] Ma Zonghong, Zhang Tao, Ding Junjie, et al. Preparation and properties of ink carbon nanoparticles reinforced chitosan composite membrane [J]. Materials guide, 2017, 31 (S2): 182-185

[10] Yang Ling, Wang weiqi, Guo qianqiong, et al. Bisphenol a sensor based on nano gold / graphene chitosan ionic liquid / L-cysteine coated CdTe quantum dots [J]. Chemical sensor, 2013 (04): 43-50.