Research Progress of Polyvinyl Alcohol Foam in Biomedicine

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Abstract. Polyvinyl alcohol (PVA) foam has strong water absorption and retention, good biocompatibility and economy, and is environmental friendly. It can be applied to different medical clinical fields by adding modifiers to impart excellent performance. This paper reviews the research progress of PVA foam in biomedicine and introduces the application of PVA foam in negative pressure wound therapy, hemostatic material, cell culture material and cartilage substitute material, and military and civilian integration combing with war wound rescue.

1. Introduction
With the aging of population, the increase of trauma in the real combat training of the troops and the improvement of people's health awareness, biomedical materials have developed rapidly. Biomedical materials refer to functional materials which could diagnose, treat, repair and replace their pathological tissues or organs. The basic requirements are non-toxic and have good biocompatibility instead of putting negative impacts on the body. It could be divided into degradable and non-degradable material. However, due to the immunity of human body and the defects of material, many materials do not meet the clinical needs well in terms of functionality, immunity, and service life.

The PVA polar foam is pure white and has a through-hole structure in which three-dimensional spaces interpenetrate each other. It can be made into blocks, thick plates or molded products. The density is generally 9.6-32kg/m³. The processing process of PVA is divided into two parts: foaming and forming. The traditional foaming methods mainly include mechanical foaming, chemical foaming, pore former foaming and physical foaming. As for foaming method, it mainly includes compression molding, melt extrusion molding, injection molding and fused deposition molding. In addition, new technologies such as nitrogen dissolving technology, freeze drying and supercritical fluid processes have emerged.

PVA foam has good properties of liquid absorption and retention besides the characteristics of abrasion resistance, chemical stability and biocompatibility [1]. It has been widely used in traditional food packaging, textile, construction, medicine, Printing and papermaking [2]. In recent years, PVA foam has gradually been applied to biomedical applications with the continuous development of technology.

2. PVA foam in biomedical applications

2.1 Medical negative pressure drainage materials
When patients suffer from various skin wounds, smashes and ulcers, the tissue fluid will seep out from affected area, which will easily breed the bacteria and hinder the recovery of the wound. Nowadays, it is wiped and removed by medical sanitary cotton, but the adsorption capacity is limited because cotton fiber is easy to fall off. what’s more, it may cause secondary damage to the wound if wiping force is too large. Negative pressure wound therapy is a new approach to accelerate wound healing in recent years. At first, it is a new type of medical technology that uses a sponge and drainage tubes to form a sealing area on the wound surface by connecting with a negative pressure source, so that the exudate of the wound is drained continuously, providing a dry and clean environment for wound recovery. It is widely used in surgery, orthopedics and other fields.

The hydroxyl group in the PVA molecule and the open-cell structure of the material itself contribute to excellent water absorption and retention. The amount of water absorption is usually 6-8 times of its own mass, up to 30 times. The PVA foam is hard and has high mechanical strength in dry state while soft in wet state. As a kind of negative pressure drainage material, it can well avoid the problems caused by medical sanitary napkins. Many scholars worldwide have used PVA foam dressings to explore the negative pressure treatment.

Matan Or[3] used the dog as the experimental object to study the application effect of PVA foam in negative pressure drainage through skin tissue transplantation experiment. The results show that PVA dressing can effectively fix the transplanted skin and keep away from Contamination in air environment. It is conducive to the growth of granulation tissue and reduces the risk of skin tissue necrosis.

Lore L. Van Hecke[4] vaccinated Pseudomonas aeruginosa and Staphylococcus aureus in the abdominal muscle tissue of the horses, and applied polyurethane foam, silver solution polyurethane foam, PVA foam and Polyhexamethylene biguanide non-stick dressings to the wound tissue respectively to compare the antibacterial effects of the four dressings in the treatment of negative pressure drainage. It turns out the amount of bacteria treated with PVA is significantly less than that of the other three dressings.

BEIJING KELINA New Material Technology Co., Ltd. produced PVA foam with ultra-mesh network structure with advanced supercritical fluid technology. The products obtained ultra-high water absorption rate and magnification with its unique “bubbling in bubble” structures. It can be used as brain cotton tablets during surgery, gynecological stuffing sponge sticks and so on.

Yang Xuekang [5,6,7] of the Fourth Military Medical University used PVA foam as the matrix to invent the dressing device which could work as Pediatric hip burn skin grafting device, post-body burn wound dressing, and special dressing dressing after limb disconnection. These targeted dressings are potent and broad-spectrum anti-infective. The wound exudate flows out through the drainage tube, keeping the wound clean and promoting wound healing.

In addition, different excipients can be added into foam according to different medical applications to promote wound healing. Patricia M. Coutts[8] produced gentian violet/methylene blue/PVA antibacterial foam dressing to treat diabetic foot ulcers and chronic stagnant leg ulcers. The results show that the foam dressing has antibacterial effect, can absorb excess exudate and reduce the frequency of dressing to improve wound healing and reduce the cost of care. At the same time, the patient reflects that the wound becomes smaller and cost less pain.

Lin Zhidan[9] added the modifier chitosan to the preparation of polyvinyl formal foam to get a kind of modified PVA foam with good water absorption performance. The effect of hemostasis and wound recovery on experimental animals was studied as a hemostatic material. The results show that the product can be antibacterial and anti-inflammatory, meanwhile, prevent wound adhesion and promote healing.

2.2 Hemostatic material
The battlefield environment is changing rapidly and the war-wound rescue of combatants is the key to maintaining the combat effectiveness of the troops. It is very common to get bloody injuries during individual combat. The rapid and effective hemostasis of incompressible bleeding is of great
importance to control bleeding and reduce mortality. The injured persons will shock or get wound infection if they are not treated in time. Effective first aid to stop bleeding can win valuable time for the rescue and reduce the mortality and disability of the wounded. Traditional methods of hemostasis such as partial compression dressing of wounds, dressing stuff, tourniquets and hemostats are all limited by pressure hemostasis. They have been proven to have limited effect on irregular and deep-cavity caused by small-caliber weapons, shrapnel or explosive devices. Hemostasis to stop bleeding at the cost of blocking the bleeding plane at the cost of tissue blood flow, may cause serious complications of distal tissue ischemia and metabolic abnormalities. For example, tight binding will compress local tissue and cause distal muscle ischemic necrosis; nerve dry ischemia injury can cause severe pain; severe cases can lead to compartment syndrome, toxic metabolite aggregation, aggravation of shock and renal failure. [10].

PVA foam can be widely used in hemostasis materials of clinical medicine by rapidly absorbing water, agglutinating cells and proteins in wound blood and promoting blood clot agglutination. At present, the main products includes sterile cotton swabs, hemostatic stuffing sponges and applied to otolaryngology, gynecology and trauma surgery. It can be processed into any shape such as a round block or a sheet as required and gradually replaced cotton wool [11].

Nowadays many scientists increased the hemostatic effect by adding hemostatic substances to the preparation of PVA foam, such as chitosan, alginate and oxidized cellulose. Yi-Fan Zhao [12] added the chitosan to the PVA foam foaming cross-linking process to prepare a novel PVA foam. Chitosan has good biocompatibility and antibacterial properties working as an ideal material for wound healing which is widely used in biomedical fields. The main mechanism is to adhere to moist tissues strongly and seal of injured blood vessels. The in vitro and in vivo hemostatic tests on rats and minipigs turns out the products are of rapid aspiration rate and strong liquid absorption capacity, which could improve blood coagulation ability, promote wound healing, and have good hemostasis in incompressible hemorrhage of acute trauma and ballistic injury.

Yansen Wang [13] prepared a porous PVA/alginate composite foam with a volume expansion ratio of 2000% by cross-linking and freeze-drying process, which not only can absorb plasma quickly, sodium alginate can also stimulate blood cells and promote blood solidification. In addition to its high flexibility and shape adaptability, it can be fully filled according to the shape of the wound and is suitable for deep and irregular wound treatment.

Andrea Melis [14] compared the PVA sponge, oxidized cellulose / PVA sponge; polyethylene film / PVA sponge in the endoscopic sinus surgery hemostasis, finding that polyethylene film / PVA sponge can reduce pain but has a higher bleeding rate during surgery while oxidized cellulose/PVA sponge has excellent hemostasis but is not effective in relieving pain compared to each other after clinical trials and patient evaluation. Polyethylene film/PVA sponge is suitable for the middle nasal passage and oxidized cellulose/PVA sponge is suitable for the nasal cavity to reduce pain and bleeding in the affected area.

2.3 Cell culture materials
Cell culture refers to a method of simulating in vivo sterility, suitable temperature, pH environment and certain nutrient conditions in vitro to support cells to survive, grow, reproduce and maintain major structures and functions. Cell culture medium is not only the basic material for supplying cell nutrition and promoting cell reproduction, but also the living environment for cultivating cell growth and reproduction.

Barbetta A [15] developed a new type of PVA as a scaffold for physiological matrix components, which simulates the real living environment to culture hepatocytes in vitro. The 3D network structure can promote cell contact and growth. PVA foams are non-toxic and have good biocompatibility and do not have any effect on cells as an inert matrix in cell culture. In this way, hepatocytes can be tested in vitro for toxicology to evaluate the effects of drugs on their metabolism.

SOON MO CHOI [16] developed a kind of PVA/gelatin macropore scaffold as biomatrix for in vitro cultured tissue. Biological experiments showed that skin tissue cells adhered and grew on the
scaffold actively. The cytotoxicity of all samples was Grade 1 or Grade 0, indicating the biosafety of PVA/gelatin as a tissue cell culture material.

2.4 In vivo stent and cartilage substitute materials

Articular cartilage belongs to hyaline cartilage which is without nerves and blood vessels. Compared with the blood supply of bone tissue damage, the blood supply of cartilage is much worse, and the environment of chondrocytes is more isolated, which makes the ability of cartilage healing very weak. At present, there is still no effective repair method to heal articular cartilage damage. There are many kinds of substitute materials for various cartilage defects. Different cartilage repair substitute materials should be selected according to the specific conditions of the patient, such as age, degree and location of injury. Cartilage substitute materials should not only have a certain degree of biocompatibility, but also have good anti-friction and fatigue resistance.

Wenting Qiu [17] used water and ethanol as blowing agents through thermoplastic molding foaming technology to prepare PVA/hydroxyapatite (HA) porous composites. The sliding friction and rotational friction experiments showed that HA was effective. The friction coefficient and fatigue performance of the material are lowered. When the HA content is 20%, the friction coefficient is reduced to 0.025, which is similar to human joint friction (0.001-0.009). When the HA content is 10%, the best fatigue durability is obtained, which could be used after 2 million fatigue cycles. Porous composites could be used as potential cartilage repair materials in terms that it is non-toxic to cells, do not inhibit cell growth and behave similarly to natural articular cartilage.

Mamatha M. Pillai [18] prepared silk fibroin (SF)/PVA scaffolds by freeze-drying. Adding 1-3% autoclaved eggshell membrane (AESM) powder as a reinforcing agent to enhance its biomechanical properties and simulate human knee meniscus, The function related to morphology, structure, mechanics and biology was tested and analyzed in rabbits. The experimental results demonstrate that the SF/PVA foam scaffold with 3% AESM showed the same compression and dynamic mechanical properties as the human meniscus, supporting cell proliferation and extracellular matrix secretion.

Kobayashi [19] found a new synthesis method to produce polyvinyl alcohol gel materials with 90% water content and 17500 polymerization degree, and confirmed that altering the water content of the polyvinyl alcohol gel can effectively adjust the viscoelasticity and change mechanical properties of material. The material is of good viscoelastic and biomechanical properties and can be used as an alternative to human meniscus.

3. Conclusion

With the improvement of medical standards and human quality of life, biomedical materials have also evolved from the earliest bio-inert materials to bio-active materials to today's biodegradable materials. Currently it is developing towards better tissue compatibility, biodegradability, corrosion resistance, durability and versatility[20]. PVA foam obtains excellent water absorption and retention properties because of the hydroxyl group and open-cell structure. The biocompatibility, economical and environmental protection makes it suitable for biomedical materials. At the same time, the strong scientific research input in the research on the war wounds and ambulances has formed a sharp contrast with the narrow application. This requires us to focus on the integration of the military and the civilian combing with the actual battlefield situation to produce the medical products which could serve the military in wartime and benefit the people's lives in daily.

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