Sutures' Structure and Application

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Contributor: xu lin, Deng-Guang Yu, Yanan Liu

With the increasing demand for wound healing around the world, the level of medical equipment is also increasing, but sutures are still the preferred medical equipment for medical personnel to solve wound closures. Compared with the traditional sutures, the nanofiber sutures produced by combining the preparation technology of drug-eluting sutures have greatly improved both mechanical properties and biological properties. Electrospinning technology has attracted more attention as one of the most convenient and simple methods for preparing functional nanofibers and the related sutures. Medical sutures refer to special medical threads used in surgery to stop bleeding, which can hold the surrounding tissues of the wound together or squeeze blood vessels to achieve hemostasis. For soft tissues such as skin, muscles, tendons and ligaments, the wound repair device used needs to be highly elastic and flexible.

Keywords: sutures ; wound healing ; electrospinning ; nanofibers ; drug delivery ; medical polymers

1.Introduction

The properties of the ideal sutures include: (1) It can maintain sufficient strength during the wound healing process, and should also be able to elongate to adapt to wound dropsy, and retract back to the original length with the wound retraction; (2) after the wound is healed, it can be degraded and absorbed by itself, leaving no foreign body; (3) no inflammation; (4) no irritation and carcinogenicity; (5) easy to dye, sterilize, disinfect and other treatment; (6) can form a safe and firm knot; (7) easy to make, low price, and can be produced on a large scale [1][2].

The increasing incidence of Surgical Site Infections (SSI) due to wound infections has led to increased treatment costs, increased hospitalization rates, longer duration of treatment, severe morbidity and high mortality [3][4]. Surgical sutures are the implantation of foreign bodies in the patient’s body, which inevitably causes tissue reactions that may lead to inflammation and other complications [5]. The source is the presence of microorganisms in the wound to form bacterial biofilm. Bacterial biofilm is a sticky membrane layer on the surface of bacteria, which is over-accumulated by a large number of bacteria and surrounded by secreted fibrin to form a collective community. Such biofilms are often found on non-living surfaces, such as hospital walls, medical devices, and implants, as well as biological surfaces, such as surgical sites, wounds and other tissue sites. There are bacterial biofilms that protect the growth of bacteria that can lead to chronic wound infection [6][7]. Chronic wound infection further aggravates the complexity of wound treatment that the use of conventional antibiotics cannot satisfy [8][9]. Methicillin-resistant *Staphylococcus aureus* (MRSA) has been reported to have caused 20,000 related deaths in the United States in 2017 alone and remains one of the important causes of infection-related deaths [10]. Common species in hospitals include gram-positive (*Staphylococcus epidermidis* (*S. epidermidis*) and *Staphylococcus aureus* (*S. aureus*)) and gram-negative (*Pseudomonas aeruginosa* (*P. aeruginosa*) and *Escherichia coli* (*E. coli*)), and it is highly desired to develop surgical sutures with excellent performance and effective antibacterial and anti-inflammatory properties. Nanofibers can play their important roles in developing new kinds of sutures to replace the traditional threads in terms of properties and functional performances such as drug delivery and wound healing [11].

At present, the method of preparing nanofibers has been phase separation [12], self-assembly [13] and electrospinning, of which electrospinning is recognized as an effective method for the preparation of nanofibers through electrohydrodynamic atomization procedures [14][15]. Nanofiber membranes prepared by electrospinning have a series of well-known advantages, such as high specific surface area, high surface volume ratio and high porosity, and their structure is similar to the human extracellular matrix, which can be effectively exploited to promote cell adhesion, proliferation, migration and differentiation [16][17][18]. During the preparation of electrospun nanofibers, it is convenient to encapsulate some bioactive ingredients such as growth factors, inorganic nanoparticles, antibacterial drugs and herbal extracts to promote wound healing [19][20][21][22][23][24][25][26][27][28]. Therefore, it is widely used not only as a polymer processing technology, but also as a facile approach to develop novel functional nanomaterials [29][30][31][32][33]. Meanwhile, the nanofiber properties can be easily manipulated by changing the relevant process parameters during the manufacturing process or using solvents with different properties [34][35][36].

2. Structure of Sutures

2.1. Monofilament Sutures

Monofilament suture is a single strand structure with a small microbial contact area, which can effectively reduce the possibility of bacterial growth. When using a monofilament suture to close a wound, multiple knots are required. In addition, only a low knotting force can be used, otherwise it is easy to break. Its advantages are that the surface is smooth and relatively easy to be knotted. Moreover, there is less resistance when passing through the tissue, which is less damaged to the tissue. Therefore, monofilament sutures are suitable for suturing contaminated wounds [37].

2.2. Multifilament Sutures

Multifilament sutures are woven together by multiple strands of threads. Braided sutures have greater flexibility and better tensile strength than non-woven sutures, but the latter have less tissue response and scar formation [5]. They are usually coated, and the suture nodules are highly firm but not suitable for usage in treating infected wounds. Multifilament sutures are not only stronger, but also have good operability, and multi-filament sutures produce better knots than monofilament sutures. Because of its special structure, less knotting is required. However, the multi-strand structure of braided sutures is susceptible to infection. Because the structure has small gaps, it can provide a place for bacteria to grow and reproduce. Moreover, compared with monofilament sutures, the structure of multifilament sutures with more small gaps allows more fluid to pass through the sutures, which is more likely to cause tissue inflammation at the wound site. A larger inhibition band can be observed when the multifilament sutures wrap the active pharmaceutical ingredient (API), such as silver or antibiotics; this indicates that the multi-gap structure of the multifilament suture plays an important role in drug delivery. The braided structure of the multifilament suture allows for a greater chance of surface coating, allowing more APIs to be adhered to than the monofilament suture. Therefore, multifilament sutures have better structural flexibility and provide greater odds for adding APIs. This makes the multifilament sutures coated with APIs have good physiological activity (such as antibacterial, anti-inflammatory, antioxidant, etc.) [37][38][39][40].

2.3. Barb Sutures

Barbed sutures are surgical sutures with barbs on the surface of the sutures to penetrate the tissue, completing wound closure without knotting the sutures. They include bi-directional or one-way/unidirectional knotless surgical sutures. The monofilament sutures are improved to make barbed sutures. The one-way barb sutures have barbs in the same direction and the needle is pressed against one end. Another type of barbed suture modified from monofilament sutures is held in place with an anchor or knot to prevent the barbs from moving in the opposite direction, which are similar to one-way barb sutures. The two sets of barbs of this suture press the midpoint on both sides of the suture opposite each other, pressing the needle on both ends for suture anchoring, and do not need a knotted circle to fix it, and is suitable for wounds that are easily separated on both sides.

Compared with traditional monofilament and multifilament sutures, barb sutures are untangled sutures. They can be absorbable or non-absorbable sutures, containing specially designed barbs that can invade tissue and fix them. Unidirectional barbed sutures eliminate the need for knotted sutures, greatly increasing the tensile strength of the sutures while also reducing tissue response. Thus, barb sutures are considered an alternative to all soft tissue closures for traditional sutures [5].

In addition, barb sutures reduce the probability of bacteria present on the sutures, thus avoiding inflammation and other complications in wounds. Although barb sutures are widely used in clinical surgery, the barb tip design of the sutures may inadvertently puncture the surgical glove, causing the infection to metastasize to the surgeon and lead to further infection of the patient's wound [41]. In addition, a cut-type barb may weaken the seam core, thinning the diameter of the seam and reducing tensile strength. However, if handled carefully, barbed sutures can exert good antibacterial activity to ensure the wound healing of skin tissue [42].

2.4. The Effect of Structure on Performance

The reasons for the failure of wound healing caused by surgical sutures have the following causes: the fracture of the suture line, the weak knot of the suture, and the frictional damage between the suture and the tissue. Among them, the low tensile properties of surgical sutures can lead to secondary cracking of the wound, the low friction properties can lead to difficult knotting and the high relaxation properties will lead to reduced suture support strength during postoperative healing [43]. The tensile strength of the suture line is closely related to its size, and the diameter of a multifilament suture is larger than that of a monofilament suture. During the weeks or months of wound healing, the strength of tissue at the wound site increases, even closer to that of the tissue before the injury. The most basic principle for selecting sutures is to use as thin and tensile sutures as possible with minimal response to tissue [44]. In this regard, many studies have shown that the diameter of the suture material increases, the creep of the material decreases. And when fibers receive different tensile strengths, the morphology of fibers will also be changed accordingly. Enough tensile strength allows sutures to be used safely, such as when they are knotted to close wounds.

Usually when a wound is sutured with sutures, there is friction not only between the sutures and the sutures, but also between the sutures and the wound tissue. If the friction coefficient is too large, it will lead to the fracture of the suture line or tissue damage, causing wound infection and preventing healing. Based on the fact that the surface of monofilament suture is smoother than that of multifilament suture. Sutures with monofilament structures or coatings can effectively reduce the coefficient of friction at the interface with the tissue. For special barb sutures, the barbs on their surface not only greatly improve the friction between the sutures and the tissues, thus avoiding the movement of the sutures from damaging the tissues. Moreover, this type of suture reduces the manufacturing cost of the suture, such as eliminating the need to add coatings to the surface of the suture to improve performance.

For the inhibition of postoperative wound infection at the surgical site, antibacterial and anti-inflammatory drugs, such as curcumin, gentamicin and nano-silver, are added to the suture material. From the three types of suture structures, it is not difficult to find that the multifilament suture is more capable of carrying more bioactive substances than the monofilament suture and barb suture. Combined with electrospinning technology, nanofibers can be given more properties to make multifunctional sutures for wound closure. All in all, the choice of suture should depend on the specific situation of the wound. Large wounds usually require more stretching and antibacterial sutures to avoid inflammation and achieve wound closure. Small wounds which in key areas usually need to avoid scarring as much as possible while effectively achieving wound healing.

3. Applications

Sutures are probably the most commonly implanted material in the human body and are widely used in all surgical fields. The purpose of suture use is to keep tissues approximate until the wound reaches sufficient tensile strength to prevent cracking during normal physiological activity. The sutured material should cause minimal tissue damage, minimal tissue response, promote primary wound healing and induce minimal scarring [45].

3.1. Tendon Rupture Repair

Healing of tendon ruptures is a major challenge for musculoskeletal injuries, and sutures play an extremely integral role in tendon repair to reduce pain and restore motor function [46][47]. Zhang et al. designed a hollow, porous, lightweight tape suture with a controllable structure for tendon repair [48]. Because of the unique structure of the suture line, the suture force pulled out through the tendon is greater. The distance between cutting tendons is smaller, and the suture has been experimentally proved to be cytocompatible and hemocompatible. There is great potential for application in tendon repair. Seo et al. prepared monofilament and multifilament collagen-hyaluronic acid (HA) sutures. Among them, the monofilament is dried on the surface of the suture line coated withCOL-HA. In addition, the multifilament suture is made by electrospinning technology [49]. Comparing the effects of monofilament and composite filament sutures on angiogenesis, cell migration and collagen synthesis in the initial stage of achilles tendon reconstruction in rabbit models, the results demonstrated that COL-HA enhances the migration of new blood vessels and cells in the body. To improve blood supply and promote tendon metabolism and nutrient absorption, Ye et al. developed a heparin-loaded core-sheath structure nanofiber that exhibited better tendon healing than commercial sutures [50].

3.2. Oral and Periodontal Surgery

The oral cavity contains a very diverse microbiome, with more than 700 species reported. Chronic periodontitis (CP) is the most common of oral diseases with bacterial etiology [51]. Most alveolar surgeries require the use of surgical sutures, and the placement and removal of sutures increases the risk of postoperative infection and bacteremia. Meghil et al. used a novel quaternary ammonium compound K21 with antibacterial effects to coat chrome catgut, polyester sutures, silk and nylon sutures, respectively [52]. However, polyester sutures appear to be more effective at lower K21 concentrations, possibly because of the increased absorbance of K21. This study has therapeutic implications for preventing postoperative wound infections.

3.3. Prevention of Corneal Repair Infection

Medical sutures are also often used in ophthalmic surgery, and it is estimated that more than 12 million sutures are used annually in eye surgeries, such as corneal transplantation, glaucoma, retinal detachment, vitrectomy and cataract surgery [53]. For 20% to 50% of post-corneal transplantation infections that cause complications, nylon sutures are often used to suture eye wounds. Based on this, it is conceivable to develop anti-inflammatory drugs that maintain sufficient mechanical strength and can load ocular anti-inflammatory drugs on the suture lines to avoid postoperative complications. Parikh et al. prepared monofilament PCL nanofibers by the electrospinning technique [54]. These nanofibers were then twisted into individual sutures, and they could continuously increase the breaking strength of the suture, while maintaining the tensile strength specified by the USP. At the same time, more small molecule drugs are loaded on the suture, demonstrating a pronounced antibacterial effect on *S. aureus*, reducing the risk of infection.

4. Conclusions

The role of sutures should not be confined to solely wound closure, but should also promote an effective wound healing in the shortest possible time, prevent infection and alleviate the pain of patients. Improving the mechanical and biological properties of the suture depends to a large extent on the properties of the polymer material used in the preparation of the suture. People are more inclined to use biodegradable synthetic polymer materials, which can not only achieve wound healing and self-degradation, but also avoid patient suffering. In the manufacturing technology of drug-eluting sutures, electrospinning technology is a good choice in order to achieve sutures loaded with a variety of drug active ingredients, and to continuously release drugs during the treatment of wounds to achieve antibacterial and healing effects. With the continuous development of electrospinning technology, there will be more and more higher performance nanofibers in the future to promote the medical use of medical sutures. However, it has the disadvantage of the inability to produce, and there are still challenges in the mass production of medical sutures through electrospinning technology.

The prevention of the occurrence of postoperative infection and other complications is always a key element to be considered in developing new types of sutures. Today, with the rapid development of the current intelligent manufacturing technology, the combinations of medical sutures with sensing technology to develop intelligent sutures will become a major breakthrough for future smart sutures. Those smart sutures will not only automatically tighten tissues without human intervention to heal wounds, but also will provide real-time monitoring during the healing process for more precise treatment results.

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