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Review Article

Recent Innovations in Textile Sutures - An Approach towards Improved Surgical Procedures -

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Abstract

The present age is witnessing revolutionary polymeric textile implantable devices which have set in new trend in traditional materials and methods of surgery. Such scientifically advanced polymer materials have been designed for particular needs in surgical and interventional procedures. Investigations have been carried out to study properties of suture materials so as to enable surgeons make proper choice of sutures for particular surgical end uses. Damaged tissues have been repaired through use of absorbable suture that close the edges of a wound or incision. Non-absorbable sutures have been made to remain permanently in the body or removed after certain duration of healing. It holds valid for sutures of similar chemical nature and of various geometric construction, like Ethilon aganist Nurolon. Silk sutures have been treated with natural fungal pigment of varying concentrations to study its influence on the properties of silk sutures like tenacity, knot strength, friction and antimicrobial activity. The finding revealed that the pigment concentration in the chosen range did not considerably influence the suture properties considered. With the increase in the pigment concentration the antimicrobial activity also increases as pointed out by antimicrobial test results against select types of bacterium. The stages involved in the synthetic suture production include filament manufacturing process, suture needle fabrication and sterilization. Review has been done relating to the raw materials, production phases of sutures, design of suture, insertion process and geometry of suture needle. For over 50 years biomedical textiles and fiber-based implants (BTFIs) have commonly used for clinical purpose to enable healing of the different types of biomaterials used, silk - based biomaterials have been widely used clinically and are being increasingly considered for its potential as biomedical textiles.

Keywords: Barbed suture; Biodegradable; Antimicrobial; Fabrication; Polymers; Silk based biomaterials

INTRODUCTION

The medical textile industry has diversified with new materials and innovative designs. Evolving polymer technology has yielded a wide range of applications of implantable medical textile devices or biotextiles. King has defined biotextiles as: "structures composed of textile fibers designed for use in specific biological environments (e.g. surgical implants, biomass reactors), where their performance depends on their interactions with cells and biological fluids as measured in terms of their biocompatibility and biostability [1]. Sutures are the most common biotextile implantable devices due to their diverse usage in surgical procedures. They are used to achieve wound closure whenever tissue separation has occurred due to an incision, puncture, abrasion, or other injury. The term 'suture' refers all materials that put severed body tissues together and to hold them in their normal position till healing occurs. In the area of medical textiles, sutures are used for surgical purpose and are growing in demand in joining of various kinds of tissues. Sutures are used to re-approximate the divided tissues and ligation of the cut end vessels. If the suture fails to perform the above said functions, the consequences may be disastrous. Massive bleeding may occur when the suture loop surrounding a vessel is disrupted [2]. Wound closure using suture materials is an integral part of the surgical process. Sutures are natural or synthetic textile biomaterials widely used in wound closure, to ligate blood vessels and to draw tissues together [3]. Sutures consist of a fibre or fibrous structure with a metallic needle attached at one of the fibre ends and they can be classified into two broad categories namely absorbable and non-absorbable sutures. Medical textile industry has diversified from conventional textile industry with new materials and developments. Revolution of polymer technology gives a wide scope to manufacture the implantable medical textile or bio-textile products. Application of the implantable medical textiles ranged from bioprosthetic (heart) valves to wound closure devices (sutures) [4]. Sutures are the most common implantable medical textiles which are used in surgical procedures. They are used to close the separate tissue which has occurred due to an incision, puncture, abrasion etc. Biomedical textiles and fiber-based implants (BTFIs) manufactured using textile-forming technologies have been in routine clinical use to facilitate healing for nearly five decades [5,6].

Properties of surgical sutures and applications

Either knot or barbed suture, which has been developed quite recently are meant to secure wounds. In order to secure best tissue closure strength sutures should be knotted. The goal of wound closure is to bring the edges of the wound together not only with sufficient strength to prevent dehiscence, but also with a minimal residual tension and compression of the tissue [7]. The example of suturing which helps in joining of two tissues is shown in figure. This figure shows wound before suturing and after suturing. Even though bioactive sutures have made their entry into the marketplace, further research is in progress for the development of future products. These sutures not only possess good antimicrobial activity but also anesthetic and antineoplastic properties. Some clinical trials have already been completed in Russia. This technology is likely to become commonplace [8]. The suturing materials and techniques used to reconstruct the planes can thus have a direct and determinate influence on the phases of healing, making an indepth and detailed knowledge of the physical, chemical and technological properties of suturing materials an absolute necessity. The clinical choice that, on each individual occasion, leads us to prefer a synthetic or a natural thread, a single or a multiple filament, a resorbable or a non-resorbable suture, must be reasoned and never left to chance. The thread is always used with a needle, the characteristics of which also contribute to differentiating its use in order to achieve the required results. A precise knowledge of these variables is part of the body of technical and theoretical expertise of every oral surgeon [9]. The suture characteristics can be of ideal, desirable and other categories. The ideal characteristics include properties such as sterile, all-purpose (composed of material that can be used in any surgical procedure), Causes minimal tissue injury or tissue reaction (i.e., nonelectrolytic, noncapillary, nonallergenic, noncarcinogenic), Easy to handle, Holds securely when knotted (i.e., no fraying or cutting), High tensile strength, Favorable absorption profile, resistant to infection.

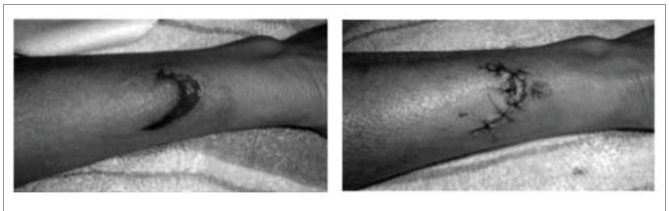

Figure 1: Wound conditions before and suturing [10].

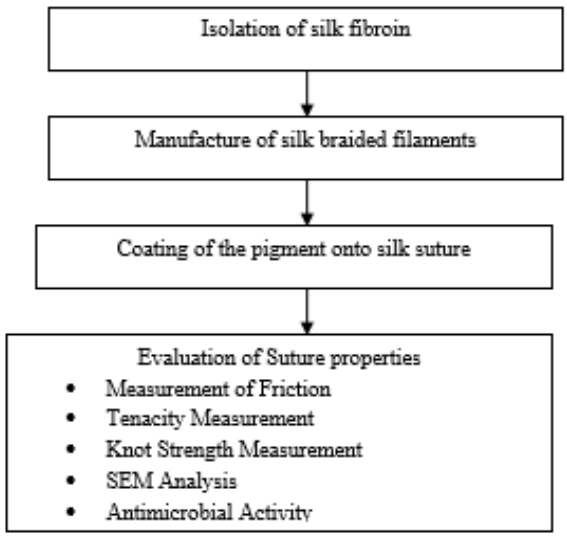

Figure 2: Silk suture development [17].

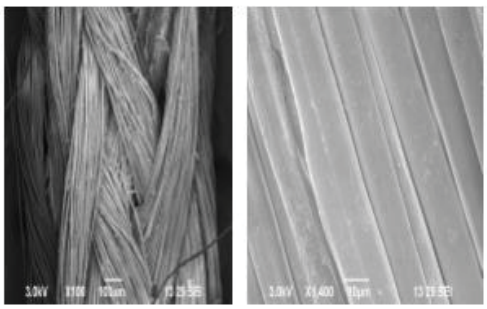

Figure 3: SEM micrograph of the pigment free braided silk sutures [17].

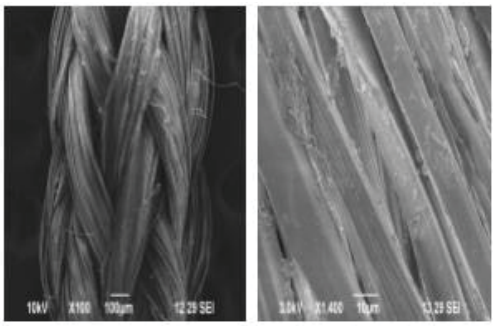

Figure 4: SEM micrograph of the 2% pigment loaded braided silk sutures [17].

Unfortunately, at present, no single material can provide all of these characteristics. In different situations and with differences in tissue composition throughout the body, the requirements for adequate wound closure require different suture characteristics. The essential suture characteristics include sterility, uniform diameter and size, pliability for ease of handling and knot security, uniform tensile strength by suture type and size, freedom from irritants or impurities that would elicit tissue reaction. Other suture characteristics include absorbable, breaking strength, capillarity, elasticity, fluid absorption, knot-pull tensile strength, knot strength, memory, non absorbable, plasticity, pliability, straight-pull tensile strength, suture pull out value, tensile strength, and wound breaking strength. The suturing technique is a complex operation involving a surgeon-specific mix of cognitive and technical components. Notwithstanding the surgeon importance, the choice of the correct suture is fundamental for tissue healing and patient recovery. Usually, this choice takes into account the patient, the type of wound and tissue characteristics and also the anatomic region. An inelastic suture cannot be placed to the area where the tissues or incision subjected to stretch often. Proper designing of sutures make it possible to sharply reduce the percentage of postoperative complications and correspondingly to reduce the number of repeated operations. Simultaneously, the time for treating surgical patients will be shortened and expenses for treatment will be reduced [10]. The physical characteristics of a suture comprise the diameter and configuration, capillarity and hygroscopicity, friction, tensile strength, knot strength, elasticity and creep. In certain cases fulfilling the suture characteristics is quite difficult for contradictory requirement. For instance, high friction is needed for better knot security, but on the other hand it increases the tissue drag. Critical requirement of suture materials are knot security, bio compatibility, degradability etc, and depending on application suture needs high elongation, and recovery, fatigue resistance etc. However, strength and diameter of the suture are the only physical properties available to surgeon. For proper choice of material other specific properties like extensibility, creep, relaxation behaviour of material, biodegradability should be known for specified application. Today a lot of biomaterials are available to make sutures, but it is more important to adjudge its biocompatibility. Research in material science and polymer engineering fields results new developments in surgical suture materials. Research focuses now on the drug delivery surgical suture materials [11].

Antibacterial silk sutures using herbal extract

As regards the suture materials, their physical and mechanical properties, handling properties, biocompatibility, and antimicrobial characteristic are of utmost importance [12]. As of now, no suture material has been able to satisfy all these properties [13]. The present surgeon has several choices of suture material available and he may choose them based on availability and his familiarity. Silk, a natural non-absorbable suture material has been used as biomedical suture for centuries due to its advantageous characteristics. However, one of the major problems associated with the silk is its poor microbe resistance characteristics. Several researchers have used different antimicrobial agents onto silk sutures to impart microbe resistance characteristics. Researchers have also used silver doped bioactive glass powder to coat silk surgical suture [14]. Recently, studies on the effect of chitosan coating on the characteristics of silk sutures [15]. Another study on tetracycline coating on silk sutures was carried out and they investigated the effect of tetracycline treatment on silk suture properties [16]. Recently, antimicrobial finishing of textiles using microbial dyes have received greater attention as they require less labour, land, and cost effective solvents for extraction as opposed to higher plant materials. In this study, silk sutures are treated with Thermomyces, a natural fungal extract and its effect on the properties of silk sutures such as antimicrobial activity, friction, tenacity and knot strength are studied. The process of development of silk suture is given below:

The following studies have been carried out,

- Effect of natural fungal treatment on tenacity and knot strength

- Effect of natural fungal treatment on friction
- Effect of natural fungal treatment on antibacterial activity
- Morphology of pigment free and pigment loaded silk sutures

Silk suture produced was treated with natural fungal extract at optimum concentration and the effects of natural fungal treatment on the suture properties were studied. The result showed that the tenacity and knot strength of silk braided sutures increased compared to the untreated silk suture. The frictional properties of both the fungal treated silk suture and the untreated silk suture were determined by the dynamic coefficient of friction and there is a slight reduction in frictional value found in the treated silk suture compared to the untreated silk suture. The uniform deposition of natural fungal pigment on to the surface of the silk braided suture was confirmed by Scanning Electron Microscopy [17]. The antibacterial activity of fungal treated silk braided suture at optimum concentration against *S. aureus* and *E. coli* is found to be good compared to the untreated silk suture. The result suggests that the silk suture treated with optimum concentration of the natural fungal pigment is appropriate to retard the exponential growth of *S. aureus*, a gram-positive bacterium and *E. coli* a gram-negative bacterium and hence silk sutures can be developed with the required characteristics for healthcare applications.

Synthetic Suture Technology for Implantable Medical Textiles

Nowadays sutures are generally manufactured using advanced biocompatible polymers. Sutures are generally manufactured using either monofilament or multifilament. In general, textile filaments (Both monofilament and multifilament) are manufactured using the following techniques [18]

- Melt spinning
- Dry spinning
- Wet Spinning
- Dry jet wet spinning and
- Gel spinning

In melt spinning process, the molten polymer is extruded through the tiny holes to form filaments. The produced filaments are stretched by an external force applied at the wind-up before the filament getting cool. Further the filament is cooled by quenching chamber where the cooled air is passed through the filament when the filament emerges from the tiny holes called as spinneret**.** In dry spinning process, the solution form of conc. polymer is extruded through the spinneret holes into the current of hot gas where the solution type of polymer is converted into solid filament by means of evaporation of solvent from the polymer solution [19]. This method is preferred where the polymers do not melt. Wet spinning is the oldest process. The fibre forming polymers are dissolved in a suitable solvent and form the polymer solution. This polymer solution is called as 'dope'. The dope is extruded through the spinneret to a liquid bath containing low molecular weight chemicals. The bath containing suitable liquids absorb the solvent present in the polymer solution and convert the polymer solution into filaments [20]. This liquid bath is called as 'coagulation bath'. In dry jet wet spinning process, the spinneret is kept in a dry state. The polymer solution extruded from the spinneret is allowed to pass through the atmosphere or inert gas and then passed into liquid bath also knows as 'coagulation bath'. In between spinneret and coagulation bath, the extruded polymer solution induces the elongation flow which results the high orientation and mechanical properties of filament. Gel spinning technique is used to produce the high strength filaments. This technique is similar to wet spinning where the polymer dope is solidified when the extruded polymer solution is passed into coagulation bath. Here the extruded polymer solution is still in gel form in the coagulation bath. The gel form polymer is passed to drawing chamber and then the filament is solidified. High Performance Polyethylene Fibers (HPPE) are produced by gel spinning. In case of synthetic suture manufacturing, due to the raw materials usage for the production of sutures, mostly, melt spinning technology is preferred. Sutures are generally classified as two types. They are absorbable and non-absorbable [21]. Absorbable sutures are used internally in the body and are designed to lose the strength over the period of time. After that, the sutures are absorbed or decomposed by the natural reaction of the body to foreign substances such as hydrolysis process. Non absorbable sutures are not dissolved by the human body's natural reaction to foreign substances. This kind of sutures is generally used for closing cutaneous or oral incisions, where the suture can be easily removed from the body. There are three major official compendiums for the suture manufacturing industry.

They are:

- United States Pharmacopoeia (USP),
- European Pharmacopoeia (EP) and,
- British Pharmacopoeia (BP).

They provide the standards and guidelines for suture manufacture. Sutures are classified as 'Medical Device' under these standards. Some important quality attributes of both absorbable and non-absorbable sutures are diameter, tensile strength, needle pull out strength, sterility etc.

The following stages are involved in manufacturing sutures and,

- Filament manufacturing (suture) process,
- Suture needle fabrication and insertion process and
- Packaging process.

Suture needles are used to safely transfer the suture material into the tissue with least amount of trauma. They are made using tempered steel. US Federal Specification GGN 211b and German standard DIN-13170 provides the performance and safety evaluation of the suture needles. They have the following characteristics,

- Suture needle is strong enough. Hence, it does not break easily,
- It should be rigid and does not bend while operation procedure,
- It has sharp edge for penetrating the tissue with minimum penetrating resistance,
- Almost it less diameter difference than suture material for minimizing the trauma in tissue and,
- It is free from corrosion and burrs to prevent infection and tissue trauma.

Sutures are one of the medical devices which are used to close the open tissue or open incision. Due to the latest development in biomaterials, the absorbable type of filaments is produced. Because

of the absorbing or degrading nature, absorbable synthetic sutures are enhancing the operation procedure [22]. They benefit both the patient and healthcare professionals. Last few decades the knotless sutures are also developed for avoiding the knotting process during the operation procedure performed by healthcare professionals.

Silk based biomaterials in biomedical textiles and implants

Biomedical textiles are defined as fibrous textile structures prepared from synthetic or natural materials that are used either in an internal or external (inside or outside the body) biological environment as a medical device to improve the health and medical condition of the patient [23-25]. These devices include non-implantable materials from wound dressings, implantable materials like vascular grafts, heart valves and sutures to wearable medical implants and polymer sensors. Medical textiles serve biomedical applications throughout the body and can provide solutions for clinical applications including general surgery, orthopedic, cardiovascular and cosmetic surgeries, tissue engineering, bariatric, dental, and veterinary needs [26-36]. Various natural and synthetic fibers are used to construct biomedical textiles. Silk, as unique natural biological proteins made by silkworms and spiders offer remarkable mechanical properties [37]. Silk-Based Biomaterials (SBBs) have been more widely used clinically as sutures for centuries and are being increasingly recognized as a prospective material for biomedical textiles. Because of the availability of large quantities of material from the textile industry, the ease of processing, controllable degradability, remarkable mechanical properties and biocompatibility, SBBs have been explored and engineered for the fabrication of various BTFIs such as sutures, arterial grafts, heart valves, hernia and prolapsed repair meshes, heart implants supports, and prosthetic ligaments and tendons, among other devices [38-42]. In order to further expand the applications of SBBs for versatile biomedical textiles, there has been interest in the regeneration of silk solutions and fibers from native silk fibers to gain even further control of properties. However, applications of regenerated silk fibers have been limited in part due to the inferior mechanical properties when compared to the native fibers. Usually, regenerated silk fibers exhibit 0.1-0.2 cN/tex (tex stands for linear density of fibers) in tensile strength while raw silk fibers from Bombyx mori , which are composed of fibroin (SF) and sericin (SS), and degummed silk fiber, mainly SF with SS removed, show 0.3-0.4 cN/tex [43-47]. Furthermore, the flexibility of regenerated silk fibers is poor compared to that of raw silk fibers. Such poor mechanical properties have been a primary reason that regenerated silk fibers are seldom used in industrial applications for BTFIs. Numerous efforts have been conducted to improve the mechanical properties of the regenerated silk materials, but to date the properties remain inferior to their native counterparts [48]. Additionally, the biological properties of fabricated BTFIs, such as biocompatibility, thrombogenicity and antimicrobial behaviour, have been enhanced with many surface modification techniques, including plasma treatment, surface coatings, chemical grafting, and encapsulation of nanoparticles [49-52]. The number of publications on the use of SBBs for biomedical textiles is increasing, however, few review papers about SBBs for biomedical textiles have been published. The present review provides a comprehensive overview of progress in SBBs for BTFIs and identifies opportunities for further development. The present review focuses on the types, compositions and physical and biological properties of BTFIs, followed by an examination of the advantages and limitations of BTFIs prepared from SBBs. The review then covers progress with surface coatings and physical and chemical modifications of SBBs for BTFIs and concludes with a discussion of critical issues, future needs and opportunities for further development for BTFIs using SBBs. A shift in population demographics, including a growing elderly population and higher obesity, affect BTFIs development. Active patients increasingly consult with surgeons about treatment options and minimally invasive surgical techniques that return them to health in a shorter time than traditional more invasive surgical procedures. To meet the increasing demand in the society, biomedical textile engineering aims to develop a holistic and integrative approach of designing and engineering BTFIs to meet biomedical and healthcare needs. SBBs, in particular, are being re-engineered with flexible and compliant textile structures to minimize the loss of natural movement. For example, the global orthobiologics market is estimated to more than double from US$ 4.3 billion in 2009 to US$ 9.6 billion by 2016 [30]. US sales of advanced DDSs have continued to grow 15.6% annually, reaching $153.5 billion by 2011 [30]. The competitive orthopaedic soft tissue repair market also is expected to grow from US$ 920 million to US$ 1.6 billion in the same time period [29]. On a worldwide basis, biomedical textile stents made from synthetic polymers using textile forming technologies have been in routine clinical use for nearly five decades and have been implanted in hundreds of thousands of patients. Although a number of areas of study are developing in the novel silk-based BTFIs, these include developments in polymer science and advanced textile solutions such as non-weaving, braiding, knitting and weaving technologies, there remain many questions for silk-based BTFIs to progress to clinical applications. First, new development needs to exploit the biocompatibility, mechanical properties, fiber varieties and fabric-forming techniques of SBBs which are required to improve silk-based BTFIs with increased value and end-use performance in the biomedical textile field. Furthermore, the development of silk-based BTFIs is a multidisciplinary field which needs in-depth research involving biology, medicine, material engineering and mathematics. The textile industry has demonstrated its competiveness in the field of biomedical and healthcare, with the development and advanced manufacturing of medical textiles, smart textiles and multifunctional textiles. BTFIs are very important in all aspects of medicine and surgery and the range and extent of applications to which these materials are used is a reflection of their enormous versatility. Among the variety of materials used for BTFIs, SBBs have been widely used clinically such as for sutures for centuries and are increasingly recognized as a prospective material for biomedical textiles.

CONCLUSION

Design of sutures is a critical aspect that determines the reduction of post-operative complications and thereby reduces further repetition of surgeries. The factors to be considered in this regard are knot security, bio compatibility, degradability and so on. Though a number of biomaterials are available, the biocompatibility becomes an important consideration. In this direction some recent researches have focussed on development of sutures that are more biocompatible compared with existing ones. Silk suture treated with optimum concentration of the natural fungal pigment is appropriate to retard the exponential growth of *S. aureus*, a gram-positive bacterium and *E. coli* a gram-negative bacterium and hence silk sutures can be developed with the required characteristics for healthcare applications. The raw materials, stages for manufacturing sutures, suture needle fabrication, insertion process and geometry of suture needle have been well explored. Silk-Based Biomaterials (SBBs) have been widely used clinically viz. sutures for centuries

and are being increasingly recognized as a prospective material for biomedical textiles. The ease of processing, controllable degradability, remarkable mechanical properties and biocompatibility have prompted the use of silk based biomaterials for various biomedical textiles and fire based implants for extracorporeal implants [53], soft tissue repair, healthcare/hygiene products and related needs.

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