

Advances in Antibacterial Textile Sutures

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Abstract

The article highlights some significant research trends in the development in antibacterial textile sutures. Braided polyamide sutures are frequently used in dermatologic surgery for wound closure. However, braided sutures promote bacteria proliferation. In order to prevent wound complications due to this effect, antibacterial sutures should be used. The major focus has been the development of new non-absorbable antibacterial polyamide braided suture. A new coating process has been proposed that leads to obtain suture uniformly covered by antibacterial film enclosing chitosan, which is known for its antibacterial benefit. Silk sutures have been treated with natural fungal pigment in varying concentrations. Also, the influence on the silk suture properties like tenacity, knot strength, friction and antimicrobial activity has been studied. Attempts have been made to systematically study the randomized, controlled trials that compare the use of antibacterial sutures (ABS) for skin closure in controlling surgical site infections.

Keywords: Braided Polyamide Suture; Antibacterial Effect; Chitosan; Wound Closure; Pigment; Fungal

Introduction

Today sutures are the most implanted biomaterials in human body because they are used in almost all wound closure [1]. They are either multifilaments (twisted or braided) or monofilament [2]. They have physical and chemical properties quite different from each other. In the last century, synthetic materials, both absorbable and non-absorbable, have been introduced in the making of surgical sutures. 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. Surgical site infection (SSI) is an immense burden on healthcare resources even in the modern era of immaculate sterilization approaches and highly effective antibiotics. An estimated 234 million various surgical procedures, involving skin incisions requiring various types of wound closure techniques, are performed in the world, with the majority resulting in a wound healing by primary intention [4].

Braided Polyamide Suture Coated with Chitosan-Citric Acid Biopolymer

In the last few years there has been a growing interest in the improvement of absorbable sutures. Quite recently, considerable attention has been paid to marketed non-absorbable sutures, which have undergone some improvements in their mechanical properties. However, there have been no new significant improvements in their physiological properties since their first use. Several researches have appeared in recent years verifying that the presence of suture significantly enhances the susceptibility of surrounding tissues to infection [5,6]. Indeed, many distressing complications such as infection, wound disruption and chronic sinus formation occur in sutured wound. Previous studies indicate that suture materials vary in their propensity to produce bacterial infection in surgical wounds. The physical configuration of the suture thread has been suggested to be an important factor in determining its susceptibility to surgical infection. Thus, multifilament suture have been known for their compliance leading to secure and compact knots. However, their intrinsic surface roughness and capillarity increase

the potential of wound infection [7]. Thus, sutures in multifilament form result in higher wound infection than the same sutures in monofilament form. To solve this problem, many researchers have proposed various methods to develop antimicrobial non-absorbable multifilament sutures by using antimicrobial agents, compounds that have the ability to kill or inhibit the growth of microbes, thus preventing infection [8-10]. These include: antibiotics that are capable of inhibiting life processes of all foreign organisms and antibacteria that kill and prevent the growth of bacteria.

Several publications have appeared in recent years, documenting several approaches to the development of antimicrobial sutures [11,12]. For several years, great effort has been devoted to the study of the incorporation of silver metal on the surface of suture and conventional antibiotics, such as neomycin palmitate, penicillin and sulfonamide, onto suture surface by impregnation. Previous research have shown that the antimicrobial activity in sutures can be achieved by blending or incorporating volatile or non-volatile antimicrobial agent while processing, coating or graft polymerization followed by immobilization of antimicrobial agents onto the suture surface [13-15]. Coating has been the most common technique used for applying the antibacterial agents on the textile surface. The antibacterial agents have been connected to the surface by physical bonds or fixed to the molecular chains of the fiber by using crosslinking agents. Focus on polyamide suture, antibiotic sutures have been developed by grafting acrylic acid onto suture surface followed by antibiotic fixation [16]. Antibiotic monofilament suture was prepared by doping with iodine and antimicrobial properties against E coli and S aureus were tested by zone of inhibition method. Drug doxycycline has been also used to obtain antibiotic suture. However, all of the previous studies do not take into account to produce commercial sutures because the frequent use of antibiotics can avoid long-term, ineffective, systemic antibiotics and reduce the risk of microbial resistant generation [17]. Based on this approach, only antibacterial compounds are recommended and used for producing suture that inhibit bacterial proliferation.

In 2004, Ethicon Inc. developed and marketed the first antibacterial sutures on the market called Vicryl Plus, Monocryl Plus and PDS II Plus. These absorbable sutures have been coated with Triclosan and have an antibacterial effect against S Aureus, S Epidermidis, Meticillin, E coli and K pneumoniae. Following the commercialization of Vicryl plus suture by Ethicon Inc, several works have been conducted and confirmed the effectiveness of this suture. Alonso et al. [18] and Rothenburger et al. [19] have also proved the antibacterial effect of this suture against S aureus and S epidermidis and Marzo et al. [20] have shown a decrease of infection with P aeruginosa germs. The success of these sutures has been also confirmed by statistical survey, proving that the use of antibacterial sutures leads to reduction in the infection frequency [21-23]. Furthermore, the use of this suture contributes to budgetary gain of \$ 1.5 million in a medical center [24].

Despite the efficiency of Triclosan, which is the most and only used antibacterial product for marketed sutures, this product has several limitations, which can cause complications. In fact, Clayton et al. have shown that Triclosan can negatively affect immune functions and the reproducibility of the cells [25]. For this reason, many attempts are recommended new antibacterial products to be used for the development of antimicrobial sutures. With this goal, in recent years, research on new antibacterial biomaterials has become very popular. Recent research reports the development of new antibacterial suture threads that show better results than Vicryl Plus [26]. Referring to the sources in general, chitosan is a biomaterial well used in biomedical field because of beneficial properties for wound healing and particularly for its antibacterial effect [27]. Several studies have confirmed the effect of chitosan as an antibacterial agent [28-33]. It is one of many antibacterial products widely present in nature. It is not affected by sterilization with ethylene oxide (EO), and keeps its antibacterial property after this treatment [34,35]. That is why chitosan is ideal for use on the development of antibacterial suture, which is subjected to sterilization by EO in the last step of manufacturing process such as polyamide suture.

The literature shows a variety of approaches permitting to apply chitosan on suture surface. Antibacterial polyester sutures have been prepared by grafting chitosan to the suture surface using acrylic acid. Much research has been done to develop chitosan coated polylactic acid (PLA) and silk sutures. Viju and Thilagavathi [36] have studied the effect of this treatment on the mechanical properties and the surface state of the braided antibacterial silk sutures. They reported a slight improvement in the suture mechanical and antibacterial properties. Nonetheless, the used dipping process does not make it possible to have a uniform treatment on the suture surface and sutures can stick between them in the bath. Although several studies have been conducted in order to develop antibacterial non-absorbable suture, today, no antibacterial non-absorbable sutures are presented in market and only antibacterial absorbable sutures are produced and marketed by Ethicon Inc. With this goal, in this study we explore the possibility of use of chitosan for the development of new antibacterial non-absorbable polyamide suture [37]. Thus, the aim of the present study was to determine optimal manufacturing conditions permitting to attain this purpose. Biopolymer compounds and non-toxic products suitable for implantation in human body will be used. Appropriate method of applying biopolymers compounds on suture surface will be presented. Chemical reactions between different biopolymer compounds and polyamides will be investigated. Mechanical, antibacterial and surface properties of sutures will be investigated in order to determine best manufacturing conditions to obtain the best antibacterial suture.

This paper is a modest contribution to the ongoing discussions on the development of antibacterial non absorbable sutures, particularly the possibility of use of chitosan for the development

of antibacterial sutures. The main purpose of this paper is the development of new process for producing antibacterial PA 6-6 braided sutures. PAD-dry process was used in order to apply uniform multilayers of chitosan-CA biopolymer on suture surface. This paper has clearly presented an investigation of chemical and mechanical properties of suture. For study purpose, chemical characteristics of applied biopolymer coating on suture surface are determined by using ATR-IF. It has been demonstrated that many eventual bonds between compounds present in coating solutions and PA-66 may occur. The existence of these bonds implies the fixation of biopolymer coating on suture surface. Suture surface has been investigated by using image analysis (SEM image) and friction difference test (FCD-mean). These experiments have demonstrated that uniform surface may be obtained by progressively applying coating solution containing little amount of chitosan on suture surface. We have also found that the developed coating process has not affected tensile properties of suture. In fact, TS and KPS still meet USP requirement. Antibacterial activity of developed sutures has been also tested against four colonies and the optimal conditions permitting to have an antibacterial effect and a smooth surface have been determined. From the research that has been carried out, it is possible to conclude that the best suture may be obtained by applying three layers of chitosan-CA biopolymer containing 1% of chitosan and polymerized at a temperature equal to 160°C. Indeed, these sutures have shown remarkable antibacterial effect against *E. coli* (gram-negative) and *P. aeruginosa* (gram-negative). Based on these results, it can be concluded that research conducted into development of antibacterial suture in vitro has been very successful. However, the main limit of the experimental results is that suture performance efficiency has not been conducted in vivo. Clearly, further research will be desirable to validate the obtained result in vivo. In an effort to prove coating film stability against friction, realized test is presented in the Supplementary

Silk sutures treated with natural fungal extract

The most crucial requirements of suture materials are physical and mechanical properties, handling properties, biocompatibility, and antimicrobial nature [38]. Till date, there is no single suture material which can fulfill all the crucial requirements of sutures [39]. 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 [40]. Recently, studies on the effect of chitosan coating on the characteristics of silk sutures. Another study on tetracycline coating on silk sutures was carried out and they investigated the effect of tetracycline treatment on silk suture properties [41].

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.

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 [42]. The uniform deposition of natural fungal pigment on to the surface of the silk braided suture was confirmed by Scanning Electron Microscopy. 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.

Sutures for skin closure in controlling surgical site infections

Skin wounds are at risk of SSI and therefore may lead to increased morbidity, delayed recovery and prolonged hospital stay [43]. The prevalence of SSI in the developed world is variable but reported figures are estimated at around 5% [44,45]. The development of SSI is a multifactorial phenomenon, which requires a multimodal approach to prevent and treat it in a timely manner to avoid financial, psychological and health-related quality of life consequences. Various predisposing aetiopathological factors for SSI include immune suppression, nutritional deficiencies, hypoproteinemias, congestive cardiac failure, hepatic failure, renal failure, use of steroids, chemotherapy agents, steroids and diabetes mellitus [46-49]. In additions to these factors, wound contamination, contaminated instruments, surgical technique and sutures used to close skin have also been reported to be responsible for SSI and cosmetic outcomes [50-52]. The prevention of the SSI by various invasive and non-invasive interventions is the most common measure surgeons and other healthcare professional advocate to tackle the problem of SSI. This includes use of prophylactic antibiotics and various other multimodal approaches already reported in the medical literature [53-56]. Triclosan [5-chloro-2-(2,4-dichlorophenoxy)phenol] is a broad-spectrum bacteriocidal agent that has been used for more than 40 years in various products, such as toothpaste and soaps. Higher concentrations of

triclosan work as a bactericide by attacking different structures in the bacterial cytoplasm and cell membrane [57].

At lower concentrations, triclosan acts as bacteriostatic agent, binding to enoyl-acyl reductase (ENR), a product of the Fab I gene and thus inhibiting fatty acid synthesis [58,59]. Use of triclosan-coated sutures should theoretically result in the reduction of SSI. Several studies have shown a reduction in the number of bacteria in vitro and also of wound infections in animals [60-62]. The objective of this article is to systematically analyse the randomized, controlled trials comparing the use of triclosan-coated antibacterial sutures (ABS) versus simple sutures (SS) for skin closure in controlling the SSIs. We aimed to include only those trials in which the SSI was investigated as a primary outcome regardless the surgical specialty. The SSI was the primary outcome of this study, whereas postoperative complications, duration of the operation and length of the hospital stay (if reported) were analysed as secondary outcome measures. Although our conclusion is based on the summated outcome of seven randomized, controlled trials, it should be considered cautiously because the quality of the majority of included trials was poor [63]. There is still a lack of stronger evidence to support the routine use of ABS but it can be considered an alternative and may initially be applied in selected groups of patients. A major, multicentre, randomized, controlled trial of high quality according to CONSORT guidelines is mandatory to validate these findings.

Conclusion

Antibacterial sutures should be used. The main objective of this study is the development of new non-absorbable antibacterial polyamide braided suture. This paper suggests new coating process that leads to obtain suture uniformly covered by antibacterial film enclosing chitosan, which is known for its antibacterial benefit. Mechanical properties and surface morphology of developed sutures were investigated by using mechanical tests. Sutures surfaces were also examined by scanning electron microscope, to perceive spreading of coating product on suture surface. In order to identify potential reactions between chemical compounds present in coating solution and suture material, sutures were analyzed by ATR-IF spectroscopy. It has been demonstrated that many eventual bonds between compounds present in coating solutions and polyamide macromolecular chain may occur. The existence of these bonds implies the fixation of biopolymer coating on suture surface. It has been demonstrated that uniform surface may be obtained by progressively applying coating solution containing little amount of chitosan on suture surface. We have also found that developed coating process has not affected mechanical properties of suture, which still meet United States Pharmacopeia requirement. Finally, antibacterial effects against four colonies, very widespread in hospitals, were studied. Prominent antibacterial effects of braided polyamide suture against two gram-positive (*S. Aureus*, *S. epidermidis*) and two gram-negative (*E. coli* and *P. aeruginosa*) colonies are presented. Optimal result of best properties is obtained

by applying three layers of biopolymer coating comprising 1% chitosan and 10% citric acid. The new developed suture coating process appears as a promising method for obtaining important antibacterial effect with smooth suture surface.

The result showed that the pigment concentration in the selected range has no significant effect on friction, tenacity and knot strength of silk sutures. Antimicrobial test results showed that as the pigment concentration increases the antimicrobial activity also increases against both *E. coli* and *S. aureus* bacteria. At 2.5% concentration, a zone of inhibition of 10 mm and 14 mm are observed against *E. coli* and *S. aureus* respectively. 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. Randomized, controlled trials on surgical patients comparing the use of ABS for skin closure in controlling the surgical site infections were analysed systematically using RevMan and combined outcomes were expressed as odds ratios (OR) and standardized mean differences (SMD). Seven randomized, controlled trials evaluating 1631 patients were retrieved from electronic databases. There were 760 patients in the ABS group and 871 patients in the simple suture group. There was moderate heterogeneity among trials (Tau²= 0.12; chi²= 8.40, df = 6 [P<0.01]; I²= 29%). Therefore in the random-effects model, the use of ABS for skin closure in surgical patients was associated with a reduced risk of developing surgical site infections (OR, 0.16; 95% CI, 0.37, 0.99; z = 2.02; P<0.04) and postoperative complications (OR, 0.56; 95% CI, 0.32, 0.98 z = 2.04; P=0.04). The durations of operation and lengths of hospital stay were similar following the use of ABS and SS for skin closure in patients undergoing various surgical procedures. Use of ABS for skin closure in surgical patients is effective in reducing the risk of surgical site infection and postoperative complications. ABS is comparable with SS in terms of length of hospital stay and duration of operation.

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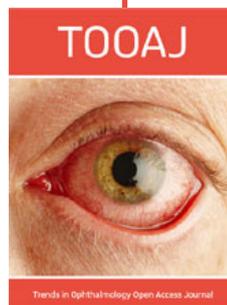
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