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Fabrication, Mechanical Characterization, and Biodegradation Analysis of Polylactic-Acid-Based Composite for Medical Sutures

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Abstract

Wound closure is surgical aids that relieve heavily on sutures, which help maintain proper tissue alignment and support healing. The effectiveness depends on factors such as the type of wound, required mechanical strength, risk of infection, and characteristics like absorbability and thickness of the martial. The efficacy of sutures is determined by their material properties and structural characteristics, which affect their mechanical properties. The primary objective of this study was to create absorbable medical sutures using a biocompatible polymer known as polylactic acid (PLA). The surgical suture made from polylactic acid (PLA) can be absorbed by human body. Furthermore, a composite suture consisting of PLA – chitosan was also developed to better performance. The suture was created through the extrusion method and followed by the stretching process to enhance their strength and structure. In recent years, synthetic polymers – such as polylactic acid (PLA) – have gained significant attention due to their controlled biodegradability and improved mechanical performance. The PLA sutures were successfully produced, and their performance was improved by applying a chitosan. The prepared sutures demonstrated good flexibility, with the capacity to stretch before breaking, and showed a crystal significance that contributes to their strength and stability. They also exhibited better knotting and trying ability, which is very important part during surgical procedures.

Keywords: Polylactic acid (PLA), sutures, chitosan, biocompatible polymer, Differential Scanning Calorimetry (DSC)

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INTRODUCTION

Medical sutures are crucial tools used in close wounds and help the healing process after surgery [1]. The suture material plays a major role as it should have the amount of strength to hold the tissue together until healing is complete. A severe wound may need to stiches multiple layers of skin needing sutures to be inserted and maintained deep under the skin. However, complication can be there if proper care is not taken. The most frequent problem is infection, which can arise from improper suture removal or wound cleaning. Other complications include hematoma, it is collection of blood under the skin and wound dehiscence, which is reponing of wound due to very tight sutures or very loose sutures. The type of suture material which is used may affect this risk.

Sutures are mainly divided into two parts absorbable (which is dissolved in the body) and non-absorbable (which need to be removed) [2]. Recent advances in suture technology have made it possible to develop “smart” sutures that can perform additional functions such as being absorbable, antimicrobial, and minimizing scarring abilities. Materials that degrade over time are used widely as they do not need to be removed and there is an associated lower risk of infection [3]. However, their relatively inferior mechanical strength susceptibility may restrict their application to certain kinds of wounds. The choice of a suitable suture is dependent on factors like the nature of the injury and the condition of the patient.

Biodegradable polymers – such as polylactic acid (PLA) – have gained attention in biomedical applications [4, 5]. PLA exhibits good biocompatibility and degrades in a controlled manner under physiological conditions. It degrades into lactic acid, which is naturally present in the human body. Due to these properties, PLA is widely used in tissue engineering, drug delivery, and surgical sutures. However, PLA has certain limitations. It is relatively brittle and has low surface hydrophilicity. These factors can affect its biological interaction and performance [6].

To overcome these limitations, composite approaches are often used. In this regard, Chitosan, which is a perfect composite, has been applied. Chitosan is a natural biopolymer with good biocompatibility and biodegradability. It also has antibacterial properties [7]. When combined with PLA, it can improve surface characteristics and biological performance. This is especially useful in surgical sutures, where both strength and compatibility are important [8].

The non absorbable sutures, like nylon or silk, remain in the body and must be removed manually after the wound has healed. Although absorbable sutures lessen the necessity for removal and decrease the chance of having long-term foreign materials in the body, they can occasionally possess lower mechanical strength than non-absorbable sutures [9].

The size of sutures is also an important factor that influences their performance. Sutures are usually classified according to the United States Pharmacopeia (USP) system that allows standard sizes according to diameter [10]. In this system, the smaller the number of zeros (for example, 4-0, 5-0, 6-0) the thinner the suture, and the larger the number the thicker the suture (for example, 1, 2, 3). Generally, smaller sutures are to be chosen because less tissue damage is caused and they are also easier to operate with and have a better corresponding strength compared to the strength of the surrounding tissue [11].

Processing techniques also play an important role in determining suture properties. Melt extrusion is commonly used to produce polymeric fibers [12]. This is typically followed by a stretching step that promotes molecular alignment and increases crystallinity. Stretching promotes molecular alignment, which in turn increases crystallinity and enhances mechanical performance [13]. As a result, mechanical strength and flexibility are enhanced. This improves handling characteristics and knot security during surgical procedures [14].

Despite these developments, there is still a need for improved biodegradable sutures. These sutures should have balanced mechanical strength, controlled degradation, and better surface properties [15]. In this study, PLA-based absorbable sutures were developed using extrusion followed by stretching. In addition, chitosan coating was applied to enhance surface characteristics. The developed sutures were evaluated for their mechanical, thermal, and biodegradation properties to assess their suitability for biomedical applications.

MATERIAL AND METHODS

Materials

A modified polylactic acid or PLA (213T grade) polymer was used as the base material in this study. This grade of PLA is recognized for its satisfactory biodegradability as well as its mechanical properties if they can be employed to make surgical stitches [16]. The important physical and mechanical characteristics for PLA 213T are that the density is 1.30–1.4 g/cm^3, tensile strength is greater than or

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equal to 50 MPa, impact strength is greater or equal to 2 kJ/m^2, melt flow rate is 8–15 g/10 min, and the Vicat softening temperature exceeds 85°C. In addition, it has a low Mold shrinkage of about 0.003% which is useful in ensuring dimensional stability during processing.

Fabrication of PLA Sutures

The PLA sutures were made by using a melt extrusion technique [17]. PLA pellets were heated to the melting temperature prior to extrusion under controlled conditions to ensure complete melting. This molten polymer was then transferred into extruder hopper which was held at temperature range of 180°C–190°C. To produce continuous filament threads, the melted PLA was forced through a die. These threads were then cooled down and collected and hence came the raw PLA sutures.

Post Processing (Stretching and Heat Treatment)

After extrusion the PLA threads were rigid because they were rapidly cooled and could not be used for surgery. To improve their properties, the threads were reheated at 100°C for 10–15 seconds and at the same time stretched. Stretching improved mechanical strength while also enhancing flexibility and elongation. Because of this, the sutures became more suitable for knotting and handling during surgical procedures.

Preparation of Chitosan Coating Solution

The chitosan solution was made from 3% chitosan powder (6 g), dissolved in 3 ml of acetic acid, then to which 200 ml of distilled water was added. A trace dye was added for visualization during coating [18]. The solution was then continuously stirred for about 2 hours to make sure that the components solved and mixed homogenously.

Coating of PLA Sutures

The prepared PLA sutures were dipped in the chitosan solution and soaked for overnight (about 24 hours) for coating by unifying the stickiness on the surface. The sutures after immersion were removed and dried at ambient condition to obtain PLA–chitosan composite sutures with enhanced antibacterial and surface properties [19]. The experimental design was developed based on standard extrusion and coating techniques reported in literature.

TEST AND CHARACTERIZATION

Measurement of Thickness

The primary objective of this test was to evaluate the handling and knotting performance of the sutures [20]. For this purpose, the length and thickness of PLA-based sutures were measured before and after stretching. Thickness was measured using an electronic caliper (micrometer), while length was measured using a ruler. For accuracy, 4–5 samples of each type of suture were tested. The values of elongation (increase in length) and thickness were averaged and reported for each sample.

Examination of DSC

Differential Scanning Calorimetry (DSC) was used to study the thermal behavior of the fabricated PLA sutures. The analysis helped in identifying important thermal transitions such as glass transition temperature and crystallinity of the material. Approximately 5–10 mg of each sample was sealed in aluminum pans and heated from −40°C to 250°C at a constant heating rate under a nitrogen atmosphere. A second heating cycle was used to eliminate the previous thermal history and obtain accurate thermal properties of the sutures [21].

Analysis of Degradation

The purpose of this test was to learn how the fabricated sutures degrade in a simulated body environment [22]. Distilled water and table salt were combined in a ratio of 1100 mL of distilled water to 9 g of salt to create a saline solution. To ensure adequate mixing, 1500 mL of distilled water and 14 g of salt were mixed using a lab shaker set to 1100 RPM for 30 minutes. Because PLA degrades slowly at room temperature, to speed up the process, suture samples were put in a water bath kept at a constant temperature of 70°C. As PLA decomposes, it creates lactic acid and causes the pH level of the solution to drop, which is an indication of decomposition. At certain time intervals, the samples were removed, dried, and their change in weight was compared. The degradation was evaluated through calculation of percentage of mass loss over time by using initial and final weight of the sutures that helped in understanding their degradation behavior.

RESULT

Fabrication of Sutures

Continuous PLA filaments were obtained through melting extrusion. The initially extruded filaments appeared rigid due to rapid cooling. However, after stretching and heat treatment, a noticeable improvement in flexibility and handling properties was observed. The final sutures exhibited a smooth and uniform surface, making them suitable for further modification and testing. The obtained values closely align with previously reported PLA–chitosan sutures fabricated using similar extrusion–stretching approaches, supporting the reproducibility of the method [8].

Thickness

The thickness of the sutures was measured before and after chitosan coating. The average diameter of the pure PLA sutures was approximately 0.33 mm. After coating, the diameter increased to 0.58 mm, confirming the successful deposition of the chitosan layer. This increase in thickness indicates the formation of a uniform coating, which may contribute to improved surface characteristics and functional performance.

Mechanical Properties

The mechanical properties of the sutures improved significantly after the stretching process. The fabricated PLA sutures showed elongation of up to 148%, indicating good flexibility and resistance to breakage. These values are comparable to previously reported PLA-based sutures fabricated using extrusion and stretching techniques [8]. The improvement in mechanical performance is attributed to molecular alignment during stretching, which enhances tensile strength and flexibility, as widely reported in polymer systems [13, 14].

DSC Result

Differential Scanning Calorimetry (DSC) was performed to evaluate the thermal behavior of the sutures. The glass transition temperature of the initial PLA sample (S1) decreased from 60.18°C to 50.64°C, likely due to processing effects and moisture absorption. After stretching (S2), temperature further decreased to 48.92°C, possibly due to heat treatment.

However, after chitosan coating (S3), temperature increased to 60.48°C, indicating the influence of the coating material, which possesses a higher Tg. The crystallinity of S1 decreased significantly, suggesting a more amorphous structure. In contrast, the crystallinity increased to 27.28% after stretching (S2), indicating improved molecular arrangement and enhanced structural strength. The observed increase in crystallinity after stretching is consistent with earlier reports where stretching-induced crystallization improved molecular ordering in PLA systems [13].

Degradation Study

The degradation behavior of the sutures was evaluated in a simulated physiological environment. A gradual reduction in weight was observed over time, confirming controlled degradation behavior. During the initial 4–5 days, the sutures became brittle and started losing mechanical strength. By the fifth day, partial fragmentation was observed, indicating the onset of accelerated degradation.

Over a period of 15 days, the sutures exhibited approximately 50% weight loss. The degradation trend became more consistent after the initial phase. Additionally, the pH of the solution decreased from 6.49 to 4.42, confirming the release of lactic acid during PLA degradation. The observed degradation profile is consistent with reported behavior of PLA-based sutures under accelerated conditions [22].

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The elevated temperature (70°C) accelerated the degradation process, leading to faster loss of mechanical strength. Overall, the sutures demonstrated controlled and predictable degradation behavior, suggesting their suitability as temporary support materials in absorbable surgical applications.

CONCLUSION

We developed cost-effective, biodegradable, and biocompatible polymer-based sutures using a scalable extrusion technique. These properties enable reliable knot security and easier handling during surgical procedures. PLA-based sutures were successfully fabricated and further improved through a stretching process. The treated sutures exhibited enhanced mechanical properties, including high elongation, controlled thickness, and reliable knotting performance. These characteristics are important for practical surgical handling. Surface modification using chitosan was carried out to improve biological and surface properties. Thermal analysis confirmed that the stretching process increased crystallinity from 4.54% to 27%, indicating improved structural stability. In addition, degradation studies showed a gradual weight loss of approximately 50% over 15 days, confirming the absorbable nature of the sutures. The developed sutures show enhanced mechanical strength along with controlled biodegradation and improved surface functionality. These properties suggest their potential use as an effective and economical alternative for wound closure in various medical applications.

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