“Synthesis and characterization of Moringa coated Silk sutures for wound healing application”

By

Sajjad Ahmad

School of Chemical and Materials Engineering

National University of Science and Technology

2022

“Synthesis and characterization of Moringa coated Silk sutures for wound healing application”

Name: Sajjad Ahmad

Reg No:00000318891

This thesis is submitted as a partial fulfillment of the requirements for the degree of

MS (Materials and Surface & Engineering)

Supervisor Name: Dr. Muhammad Shoaib Butt

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

H-12 Islamabad, Pakistan

November, 2022

DEDICATION

I dedicate this thesis to my Respected Parents and my wife.

Acknowledgment

All gratitude and praises are to **Allah Almighty**, the Most Gracious and the Most Merciful. He is the entire source of knowledge and wisdom to mankind, who gave us health, thoughts, and capacitated us to achieve this goal. After Almighty Allah, praises are to His **Prophet Muhammad (S. A.W.),** the most Perfect and Exalted, and an everlasting source of Guidance and Knowledge for humanity as a whole.

I would like to express my deepest and sincere gratitude to my supervisor **Dr. Muhammad Shoaib Butt** and Co-supervisor Prof. **Dr.Attique ur Rehman**, Assistant professor atthe Institute of space and technology (IST) University who accepted me as a postgraduate student and provided me a chance to work with them. I am truly very fortunate to have the opportunity to work under their supervision and grateful for my advisement, guidance, and support throughout my work. The professional research skill and personal lessons that I have learned from them are invaluable for future endeavors. Also, I am very grateful to all my teachers who helped me and motivated me to do my best.

I am greatly indebted to all my colleagues in IST who have graciously applied themselves to the task of helping me with support and valuable suggestions. A special thanks to **Dr. Aftab Akram** and all the other senior research students for their help and support. I pay my regards to my colleagues and friends especially Muhammad Fasih, Usama Naeem, Khalil ur Rehman And Munawar Ali, thanks for the friendship and memories.

Finally, I am thankful to my family, especially my parents. Their moral help and financial support remained with me throughout these years.

SAJJAD AHMAD NIAZI

Abstract

Surgical sutures play a significant role during the wound healing of surgical site infection in the medical world. This study was done to develop novel Moringa Oleifera based polymeric composite films on the silk braided suture materials and produce an antimicrobial coating agent. Sodium hydroxide (0.1N) solution was used to pre-treat and open the structure of the sutures to allow the coating agent to penetrate the suture structure. Chitosan a natural polymer and Moringa Oleifera as an antibacterial drug are combined to get additional benefits such as prevention of surgical site infections (SSI) and wound healing. Moringa Oleifera extracts using in vitro antimicrobial screening methods. Chitosan and Moringa mixed in a fixed quantity to produce polymer-based films. The pretreated sutures were then evaluated and compared, with non-treated sutures acting as the control. The films were screened for antifungal and antibacterial activity against bacterial (P.aeruginosa, Escherichia coli) and fungal strains (Aspergillustubingensis and Aspergillusflavus) screened. Chitosan-based Moringa films showed antimicrobial activity against all the strains; the lowest Moringa concentration (5%) showed the highest activity against all the strains. In vitro antibacterial tests of these coated sutures were carried out. Through this study, it was found that the sutures coated with Moringa/Chitosan exerted a better-sustained efficacy assay compared to those that are not pretreated, have the potential to be used for wound healing.

Keywords: Surface morphological analysis; Silk suture; Moringa species; antimicrobial; Biocompatibility;

Table of Contents

List of Figures

List of Tables

Chapter:1

Introduction and literature review

1.1 Biomedical science

Biomedical science is the science in which we investigate how our human body is working at a molecular level. In biomedical sciences, we find new medical treatments for different infections. Our research expands into the area in which drug delivery is used for the treatment of different infections. The area of clinical epidemiology is under biomedical science. Biomedical science is the science that is related to healthcare and public health. The core purpose of biomedical science is the health care of the human body. Now a day's biomedical science is the broadest area of science through with we can support modern medicines. In biomedical science, we deeply analyze the human body in a normal or disease state. Diseases and their symptoms related to the human body is the major subject in biomedical science. Nowadays we have a very advancement in biomedical science we can cure diseases with much anti-bacterial and anti-inflammatory medicine especially related to the wounds healing applications. Modern medication methods are very helpful for human beings against many diseases. Microbiology is the study of living organisms such as bacteria and fungi and many other parasites which can cause infections. After investigating the infection we can cure the infection by using antibiotics or anti-bacteria drugs on the infection site

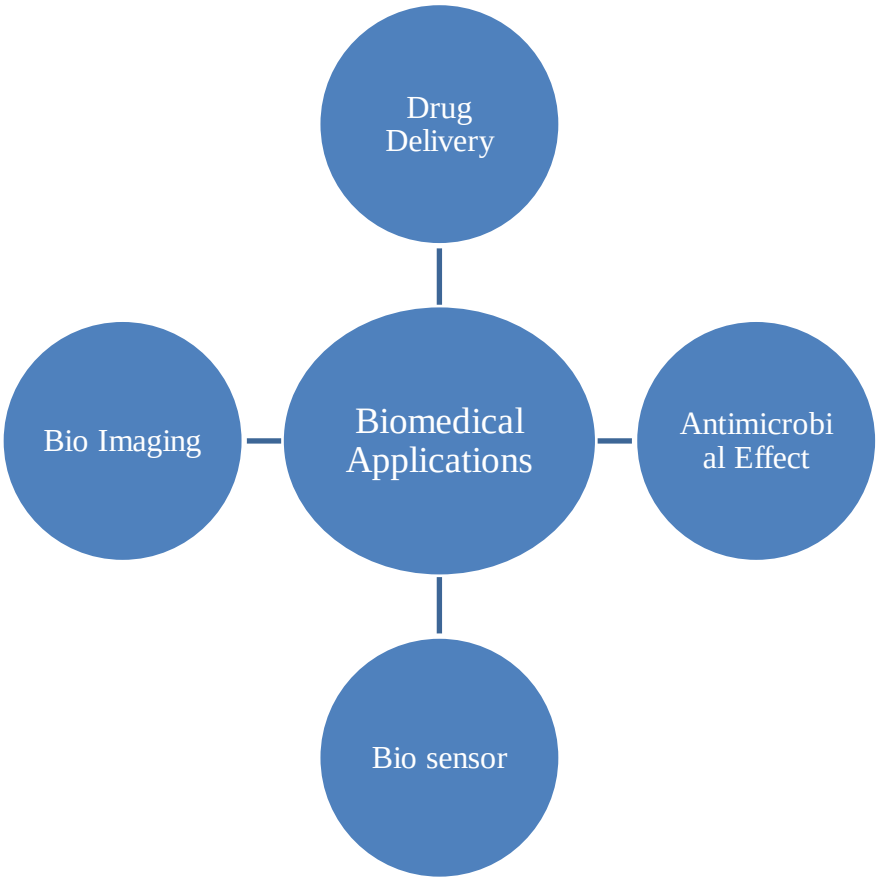
1.1.1 Types of biomedical science

Biomedical science is mainly divided into four main disciplines.

1. Infection science
2. Blood science
3. Cell science
4. Genetic and microbiology

1.1.2 Biomedical applications

Biomedical science has a wide range of biomedical applications with the help of biomedical science we can make a drug delivery mechanism. We use an anti-microbial or anti-inflammatory drug through surgical sutures for the healing of wounds. The anti-microbial effect plays a very important role against the different types of bacteria due to which the human body is suffering. Biomedical applications have a wide range of applications in bioimaging. Bioimaging is a process to visualize the functional image as well as the process of the living objects. Bioimaging is a process in which we can visualize biological activities. Biomedical science has very huge scope in biosensors. Biosensors are the devices through which we can produce a measurable signal related to the concentration of the target analysis. Biosensors are used to detect pathogens in foods. With the help of biosensors, we can detect the presence of the Escherichia coli in the vegetables due to variation in the PH value which is caused by the ammonia.



1.2 Wounds

Wounds the injury in which our body cells and tissues are damaged. Wounds can be divided into many ways depending on the wound healing time. The wound is generally categorized into two main types. Open wound and closed wound... Wounds are created due to some sudden act like a cut, a fall or knock .there are many examples of wounds such as cuts, graze and lacerations .normally cuts are created when sharp objects like knife or glass. a very sharp and narrow sheet of paper even creates cuts on the human body

1.2.1 Types of wounds

There are two types of wounds.

1. Open wound
2. Closed wounds.

Open wounds

Open wounds are the types of wounds in which the wound is open to the external atmosphere or environment. Open wounds are the wounds in which it exposed the underlying tissues and organs the best examples of open wounds are penetrating wounds and blunt force trauma .in the category of penetrating wounds we have several wounds like puncture wounds, surgicalwounds, thermal chemical, and electrical burns. in blunt force trauma, we have abrasions, lacerations, and skin tears.

Closed wounds

Closed wounds are the types of wounds in which a wound is closed that's occurred without any exposure to the tissues and organs, in closed wounds, wounds are not in contact with the outer atmosphere and environment. The major types of closed wounds are contusions,blisters, and crush injuries

1.2.2 Stages of wound healings

There are four stages of the wound healings

1. Homeostasis
2. Inflammatory
3. Proliferative

4. Remolding

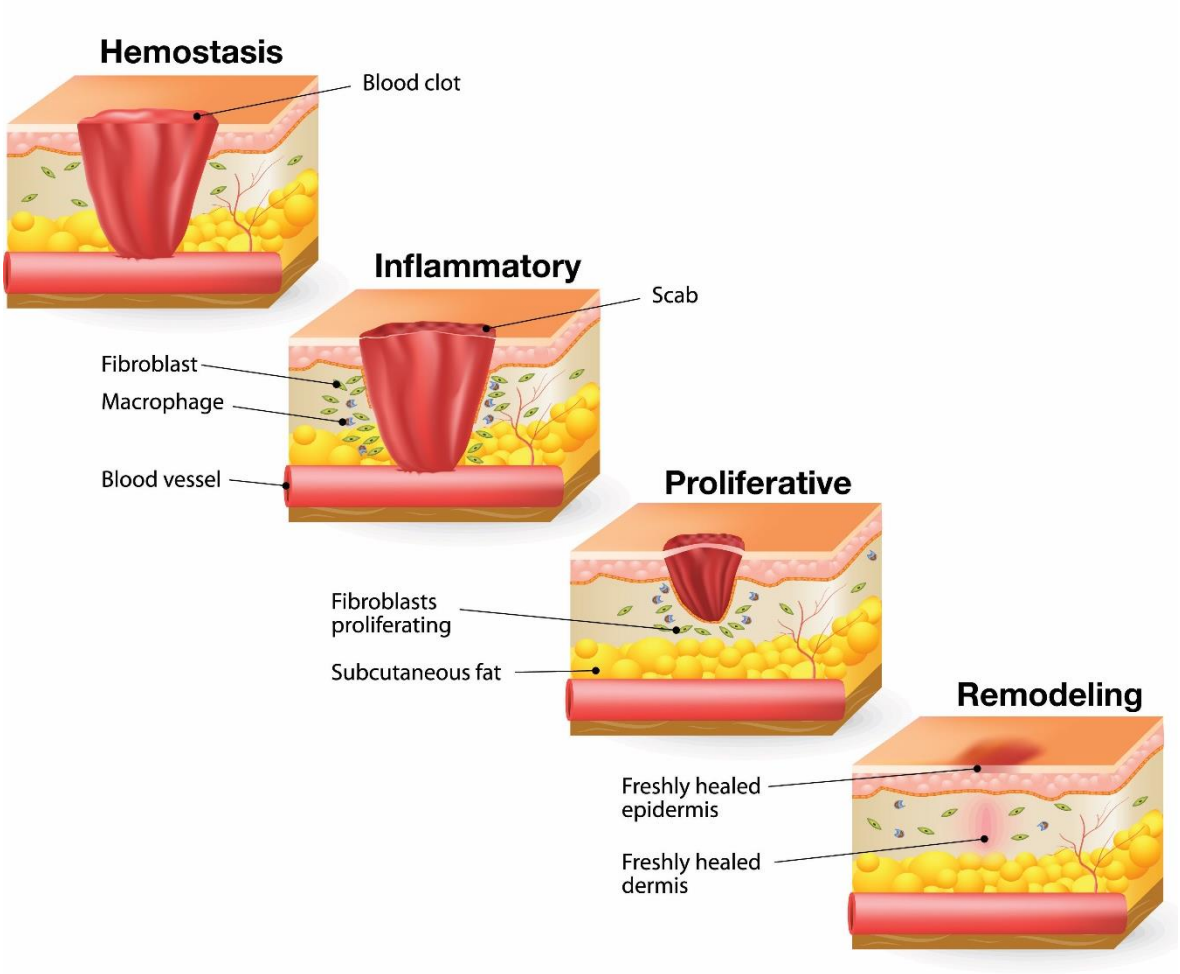


Figure 1.1 Different Stages of wound healing

1.2.3 Treatment for the healing of wounds

- Cleaning to eliminate soil and flotsam and jetsam from a new injury. This is done tenderly and frequently in the shower.
- Immunizing for lockjaw might be suggested sometimes of awful injury.
- Investigating a profound injury precisely might be important. The nearby sedative will be given before the assessment.
- Eliminating dead skin carefully. Neighborhood sedative will be given
- Containing enormous injuries with lines or staples.

- Dressing the injury. The dressing picked by your PCP relies upon the kind and seriousness of the injury. In many instances of constant injuries, the specialist will suggest a sodden dressing.
- Relieving pain with medications.
- Take as directed prescribed antibiotics and antimicrobial dressings.
- Some medications, such as anti-inflammatory drugs and steroids, interfere with the body's healing process.

1.3 Surgical sutures

The most common name of sutures is stitching. we use the sterile surgical suture for wound healing. use of suturesdepends on the type of wound. Some wounds required alternative methods like metal staples instead of sutures

Surgical sutures are vulnerable to bacterial infections and biofilm formation [1]. At the suture site, pain and undesirable, excess inflammations are additionally detrimental to wound healing [2]. The development of a Moringa coated surgical suture introduces the capability to locally deliver both anti-inflammatory and anti-microbial drugs. The most common therapeutic class used for prophylaxis in patients who develop SSI is a cephalosporin (73.2%) with third-generation cephalosporin administered in 60.7% of the patient [3]. These infections are usually difficult to resolve and may cause complications in extreme cases. To prevent surgical site infections, scientists have been using several natural and synthetic materials like plant extracts and polymers which may be used as coating materials on the surface of medical devices such as surgical implants or sutures. [4]. The addition of antibiotics to these coating biomaterials can provide the local delivery of antibiotics directly at the implantation or suture site, thereby decreasing the onset of infection. [5]. The main objective of this study is to focus on the development of novel natural anti-inflammatory-based polymeric composite films and antimicrobial Silk braided suture coatings. A natural, biocompatible and biodegradable polymer will be combined with a natural herb as a drug-eluting to exploit its antibacterial and anti-inflammatory properties as shown in Fig 1. The properties of these two materials will be

combined to get additional benefits such as wound healing and prevention of surgical site infections [6]

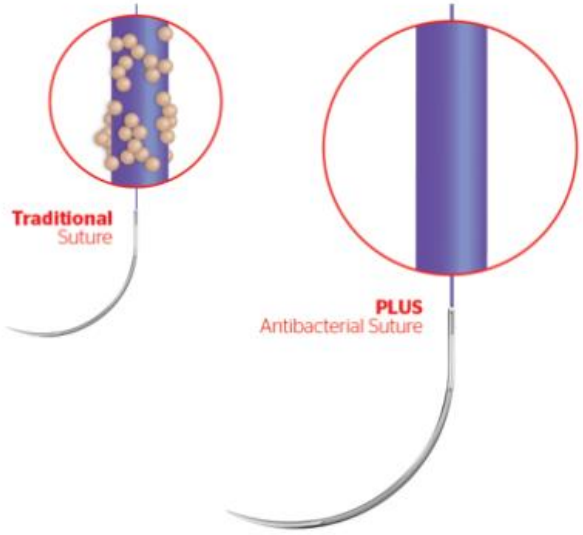


Figure 1.2 The traditional and antibacterial coated suture

Surgical sutures

Surgical sutures play a very important role in the healing of tissues of the body after injury or surgery. Surgical sutures have a variety of different sizes and materials. The usage of surgical sutures depends upon the suture site. There are two main types of surgical suture, absorbable or non-absorbable sutures. Absorbable surgical sutures are the surgical sutures that degrade they do not need any traditional removal like non-absorbable surgical sutures. Absorbable sutures degrade themselves within 4 to 8 weeks. Absorbable surgical suture is very effective for the internal and accessible parts of the suture sites.[7] Nowadays we can create the surgical suture which hasthe capability for wound healing biomedical application. The surgical suture includes antimicrobial and bioactive such as drug-eluting and coated sutures.besides the traditional surgical sutures now we have a market of

antimicrobial and anti-inflammatory coated sutures which have a very high potential against bacterial or undesirable inflammatory responses.[8]The very first FDA-approved antibacterial surgical suture was reported in 2002 which is made up of a polyglactin suture coated with triclosan it successfully reduced the rate of surgical site infection.This FDA-approved antibacterial surgical suture opens a door for the development of the anti-microbial and anti-inflammatory suture types.The developing protection from triclosan and a cutoff to the supported and compelling uses of Vicryl Plus has made stitch options with further developed properties be wanted. With the consideration of against microbial impacts, stitches locales would be less inclined to foster diseases, and stitches themselves are more averse to assemble biofilms, a difficult confusion of long haul bacterial colonization. Addressing contaminations and biofilm anticipation will bring about in general simpler mending for the patient, and lower clinical expenses.

Due to the limited variety of antimicrobial sutures still, infection prevention is a very major concern forany sutured wound. Patients feel pain from the wound site during stitching to avoid this pain, drugs such as anti-inflammatory are often used. Production of anti-microbial and anti-inflammatory surgical sutures localized pain relief and better wound healing biomedical applications. Now we have a coated suture which is an entirely new fabrication of surgical sutures.

The reason behind the usage of coated antibacterial and anti-microbial surgical sutures simultaneously addresses the tissues with localized drug release. The addition of direct drug delivery from surgical sutures has a detrimental effect on healing on suture sites.

The most common antibiotic is rifampicin which is an ideal anti-microbial drug used due to its very high level of efficiency and low MIC against the most common occurring bacteria strains such as E Coli and s. aureus. Resveratrol is a most anti-inflammatory molecule which is mostly found in red wine. Its free radical makes a very effective wound healing biomedical application

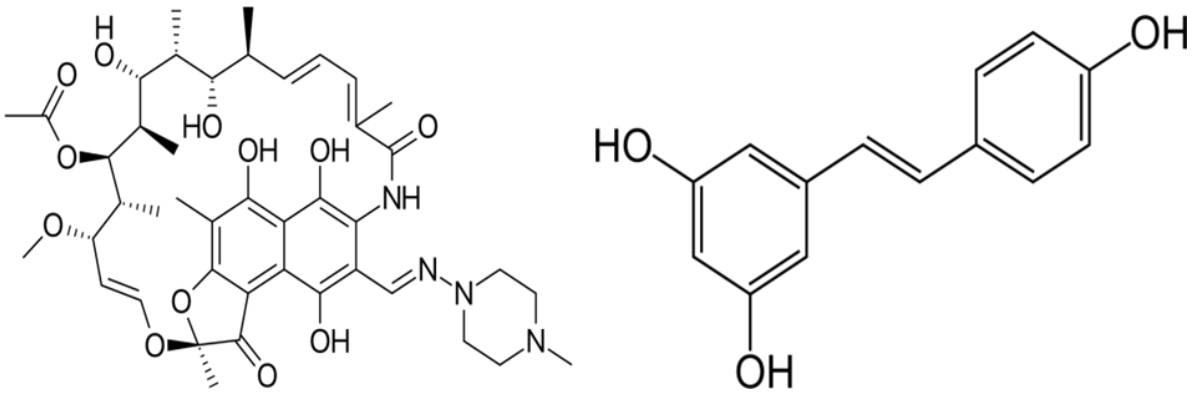


Figure 1.3 Anti-microbial molecule rifampicin (left) and anti-inflammatory molecule resveratrol (right).

This project aims to give dual drug delivery suture which shows both anti-microbial as well as anti-inflammatory effects. By doing we can improve the wound healing process for the patients' smart sutures mostly released drugs for a very short period most of the research reports' delivery time frame is almost 1-2 weeks 10. Healing of infection can be a slow process normally tissue remolding takes 4 long weeks for the wound healing process we use therapeutic drugs throughout the entire process for best healing.[9]

Most of the absorbable sutures take about 2 months for degradation and removal from the body. Depending upon the time-scaled 4 weeks is an optimum time scale for drug delivery therapeutic level.

Many of the fabrication methods of drug-eluting sutures affect the mechanical properties of the sutures. Silk non-absorbable suture handles tensile load to 20 N. While polyester and polypropylene suture take the tensile force of 11 N. Tensile strengths is one the most important property for the surgical sutures. Drugs eluting sutures at least have strength equal to polyester and polypropylene suture

1.3.1 Types of sutures

There are two types of the sutures

1. Absorbable sutures
2. Non absorbable sutures

Absorbable sutures

Absorbable sutures are the biodegradable suture. Most doctors do not require removing the absorbable sutures from the human body. Different types of enzymes which are present in our body will naturally degrade them. Absorbable sutures are usually used inside the body for wound healing. Absorbable sutures are preferred for the closed wound healing

Non absorbable sutures

Non absorbable sutures are not biodegradable sutures. Doctors remove them from the human body in the days or weeks according to the procedures. Non-absorbable sutures are preferred for the open wound healing applications

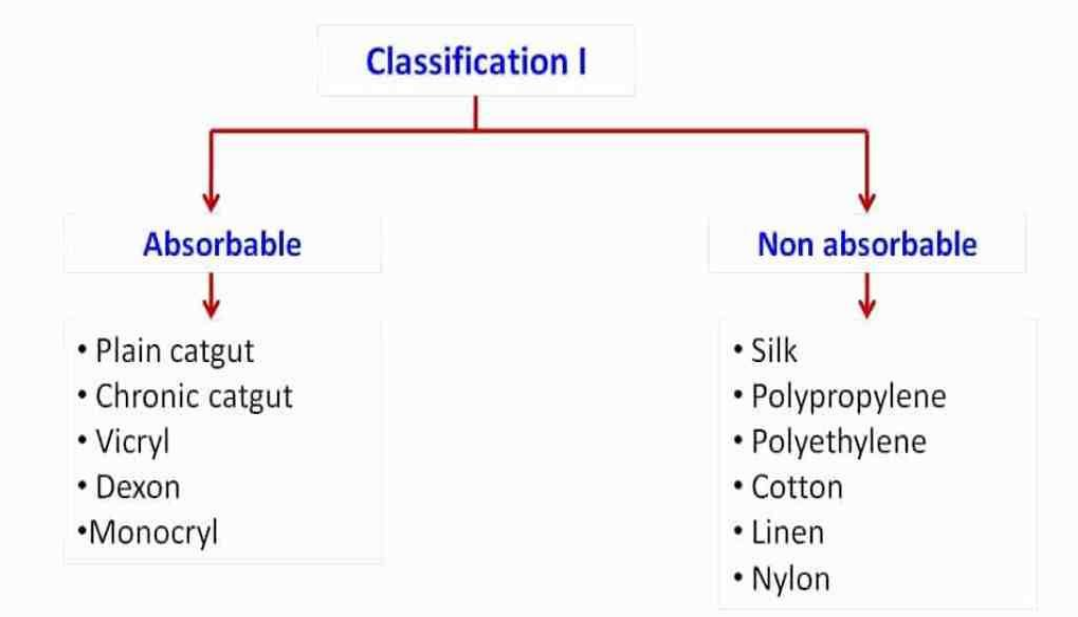
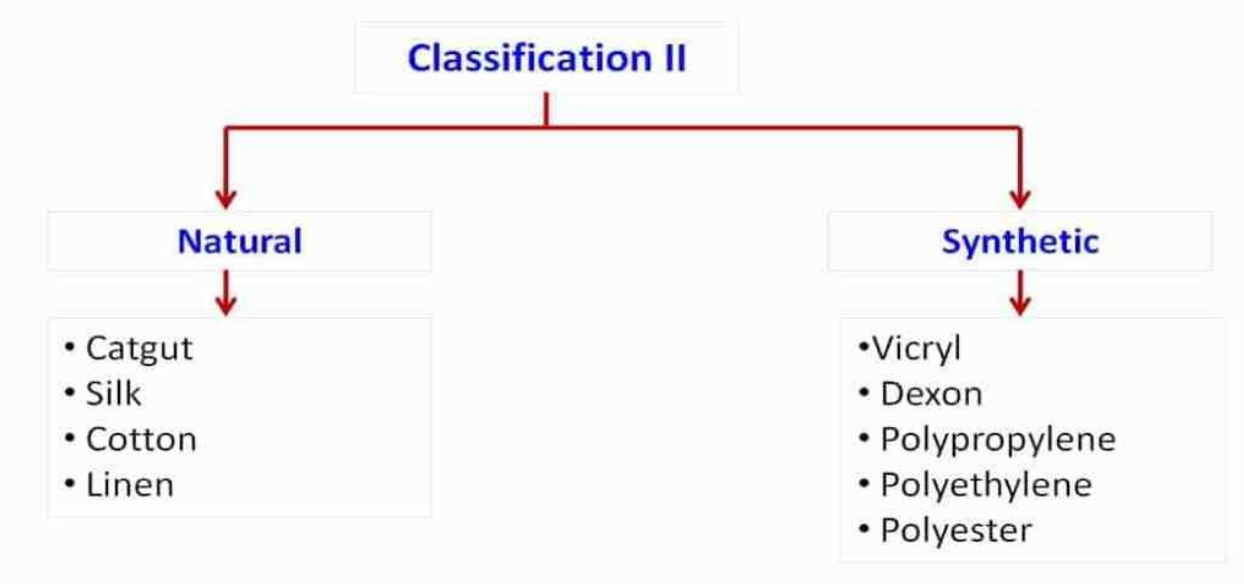


Figure 1.4 Diagram ofnon-absorbable suture

1.3.2 Sutures materials

Sutures materials are made up of different types of materials. we classify the two main categories of suture materials

1. Natural
2. Synthetics



1.3.3 Uses of sutures

We used the sutures to heal the wound. We have two types of wounds. Open wound and closed wounds. We use the absorbable suture for closed wounds. Mostly non-absorbable sutures are used for open wounds. most of the time we use alternative methods to heal the wounds like using metal staples.

Table 1.1 Different types of sutures and Different structures of the surgical sutures

Suture type	Absorbable	Non absorbable	Monofilament	multifilament
Silk	NO	Yes	NO	yes
Vicryl	Yes	NO	NO	yes
PDS	Yes	NO	yes	NO
Monocryl	yes	NO	yes	NO
Nylon	NO	Yes	yes	NO
prolene	NO	Yes	yes	NO

1.3.4 Structures of the surgical sutures

There are two types of structure of the surgical sutures

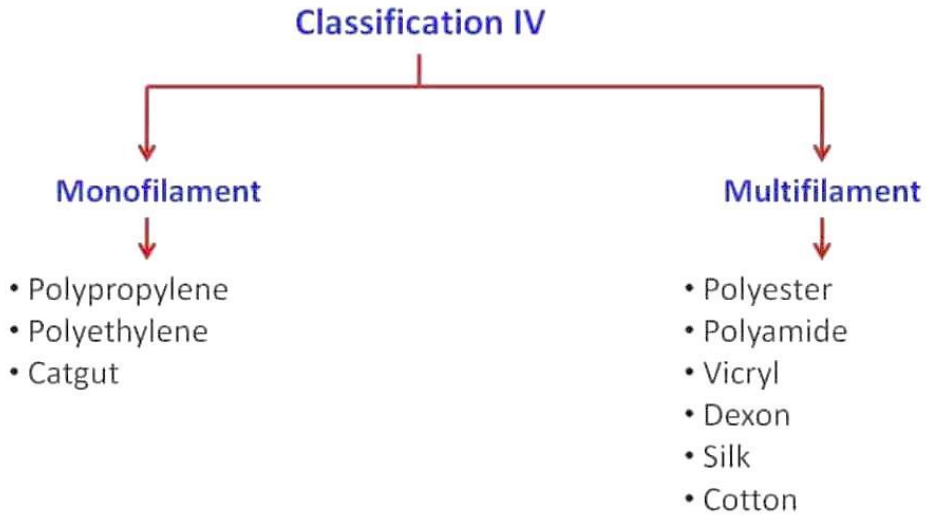
1. Monofilaments
2. Multifilament

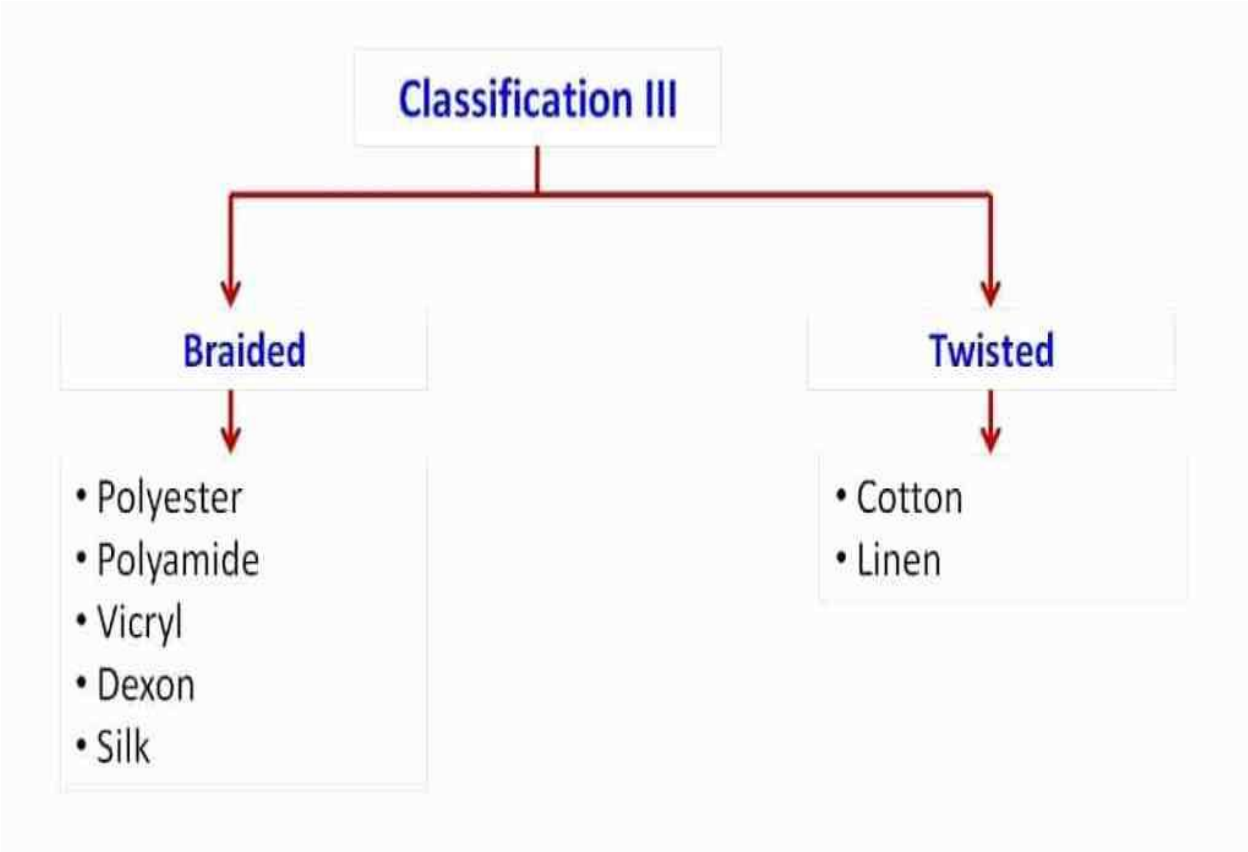
Monofilaments

Mono means single, in monofilament, there is a single-stranded filaments suture. A good example is the monofilaments are nylon and prolene. monofilament has a very low risk of infection but side by side there is a drawback in monofilament is having poor knot security and ease of handling.

Multifilament

Multifilaments suture in which we have many filaments that are twisted together. The silk branded is the common example of the multifilament suture. these sutures have ease of handling and they have a good shape for knot security but multifilament sutures have a risk of infections





1.3.5 Problems related to surgical sutures

Surgical sutures also have disadvantages due to several problems like crosshatching. It is very difficult to make fine adjustments along with the infection site. By using surgical sutures, the risk of dehiscence when the suture is removed from the human body. The complications of suture hypersensitivity depend on the type of suture material used and the tissue being sutured. In general, the extent of inflammation, congestion, and foreign body reaction may complicate wound healing in any tissue. The main disadvantage of this suture material tissue is irritation from the cut ends of the suture material.

1.3.6 Cost-effectiveness

Surgical sutures have different types of material through which they are made. Polydioxanone is the more expensive surgical suture than polyglycolic acid and polytrimethylene carbonate which is a synthetic monofilament absorbable suture. Our trusilk braided non-absorbable suture hasa price of 2.81 USD per box. Each box has 12 individual surgical sutures. Our silk braided suture has a price of 0.23USD per piece

1.3.7 Features of Trusilk

1. Natural, braided fibers of silk
2. Excellent handling
3. High knot security
4. Treated with wax/silicone for added strength
5. Commonly used on mucosal and intertriginous areas as it is soft and pliable

Trusilk is an inert, non-absorbable suture known for its smoothness and knot security. It is braided tightly to ensure better strength, performance, and secure knot placement.Since silk sutures have moderate tissue reaction, it is not suggested for use in biliary and urinary tract surgery. It is recommended for use where the least possible suture reaction is desired. The technical details are as follows:

1. Made from 100% protein fiber spun
2. Coating of wax/silicone
3. Available in black or ivory colors
4. Sterilized by ethylene oxide
5. Shelf life of 5 years

The range is as follows:

1. USP sizes available: 6-0 to 4
2. Length available with a needle: 35 cm to 90 cm
3. Needle length: 12mm to 50mm across all needlepoint profiles

1.4 APPLICATIONS

1. General surgery
2. Ophthalmic surgery
3. Cardiovascular surgery
4. Gastrointestinal surgery
5. Orthopedic surgery

1.5 Moringa and chitosan

Moringa Olifera is a natural nutritional plant. Historically the best wound healing methods include the Moringa and horseradish trees. Moringa olifera trees are located in Pakistan, India, and Mexico. Most of the studies which are related to health control or diseases show that Moringa olifera is an anti-bacterial and anti-microbial against the E Coli and s, aureus strain **.1** Moringa olifera leaves also play a vital role against diabetic patients. Moringa is anti-diabetic. Moringa is also an anti-inflammatory drug that is very helpful for wound healing. Moringa olifera is a natural nutritional as well as an optimal biomaterial with nutritional values. When we inspect the Moringa olifera leaf. The composition of the Moringa olifera includes Calcium magnesium iron zinc potassium phosphorus sodium; vitamin A B C & E**.2** Moringa olifera have the property to enhance tissue regeneration. Moringa olifera can enhance the collagens formations. Moringa also enhances the epidermis based on these properties Moringa is playing a unique role in wounding healing applications.[10]

Figure 1.5 Diagram of health benefits of Moringa

1.6 Chitosan

Chitosan molecular formula is quite similar to cellulose. Chitosan is made up of alkaline deacetylation which is composed of an n acetyl glucosamine and glucosamine. There are many properties of chitosan. Chitosan is a biocompatible. Chitosan shows antifungal as well as non-toxics behavior. Chitosan also shows a biodegradability behavior. Most of the important properties of the chitosan assists to enhance thrombus formation.

Thrombus formations mean creating a blood clot on the infection site which is best for the healing of the wound. Thrombus formation enhances the healing time of the wound.

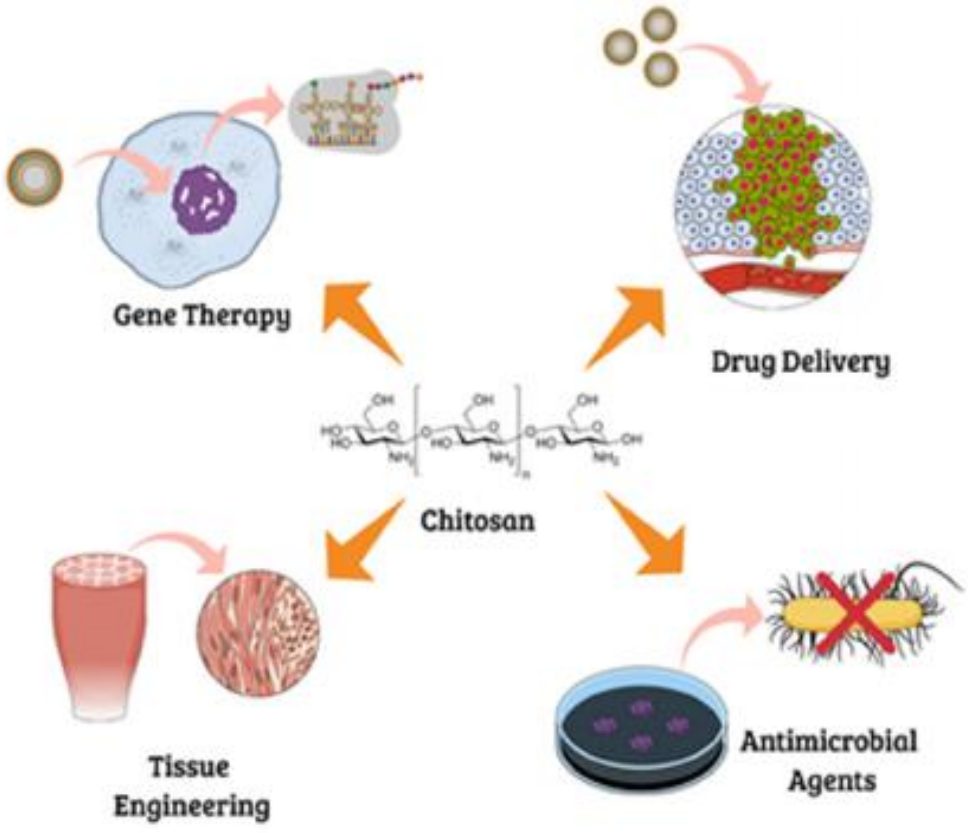


Figure 1.6 Diagram of uses of chitosan

Chapter:2

Anti-inflammatory and antimicrobial drug coating on surgical sutures

2.1 Materials

Silk braided non-absorbable surgical sutures were purchased from D Watson Blue Area Islamabad. We take theMoringaolifera leaf (MOR) from the Nursery of NUST. Chitosan was provided by Dr. Muhammad Shoaib Butt fromSCME, NUST. DC supplier was provided by Dr.AttiqueurRehman from the Biomedical lab of the institute of space and technology Islamabad (IST). Anilinewas provided by Dr.AftabAkramfrom chemical lab SCME NUST. APS ammonium persulphate was taken from the chemical lab of the school of natural science SNS NUST. All other chemicals, solvents, and reagents were available in the biomedical lab of the institute of space and technology Islamabad. E coli strain was provided by DrTahir Ahmad Baig from Atta UrRehman Schoolof applied bioscience ASAB NUST.

2.1.1 Extraction of Moringa Olifera leaf (MOR)

Fresh Moringa olifera leaves are plucked from the tree. The leaves of the Moringa olifera are washed with the tap water, after chopping the leaves of the Moringa olifera are boiled in distilled water at 100 centigrade temperatures. Leaves of the Moringa are filtered with the help of filter paper or funnel. In the next step, these choppedleaves are dried in a drying oven at 70 centigrade temperatures for 6 hours.

We use the mortar to ground the powder and crush the leaves of Moringa. After crushing Moringa powder is preserved in the container for further use. [11]

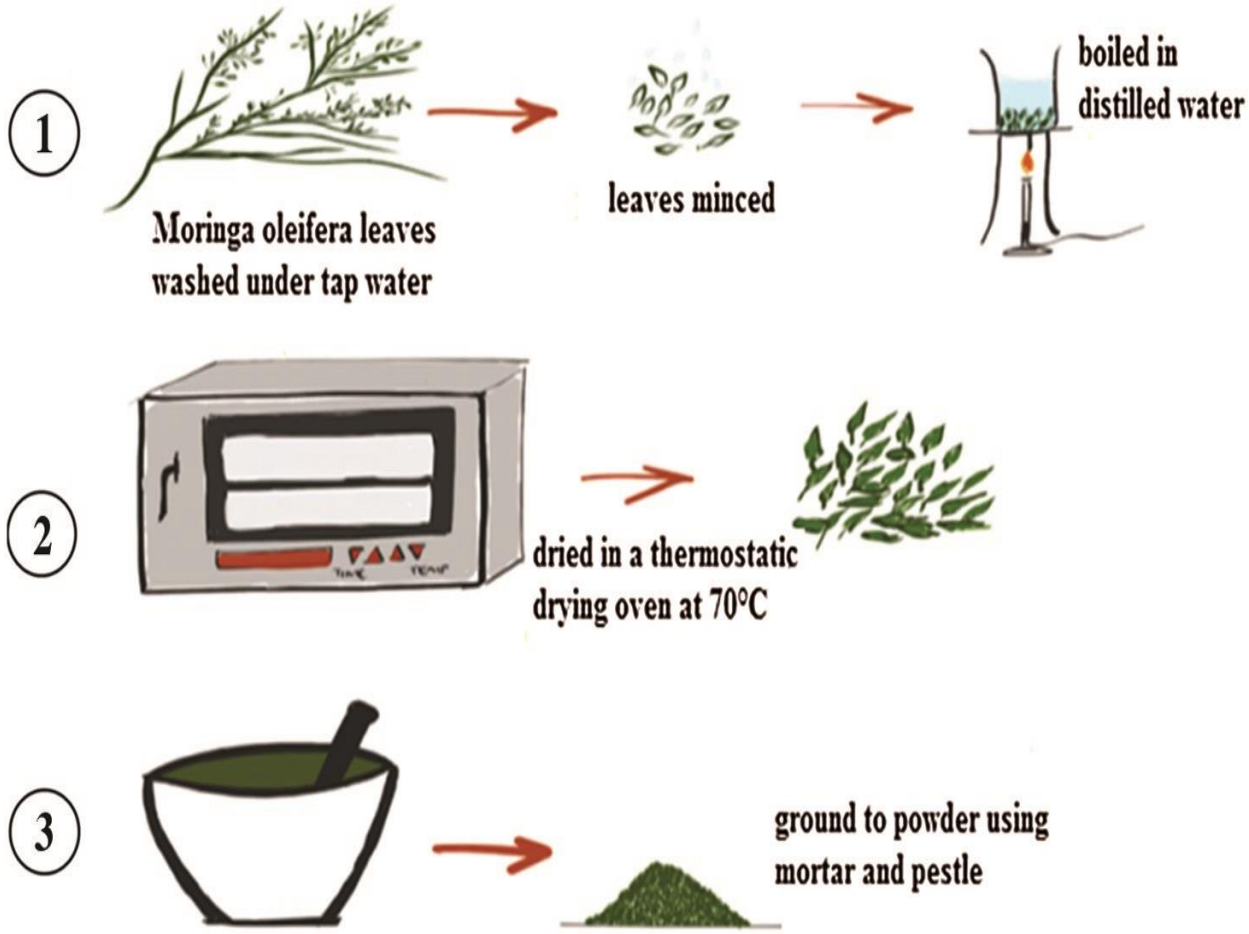


Figure 2. 1 Schematic of extraction of Moringa powder from Moringa olifera leafs

2.2 METHODS:

2.2.1 Dip Coating:

Dip coating is a coating process in which we immerse the substrate into the tank containing coating material. When we remove the substrate from the tank containing coating materials then allow it to drain. With the help of force drying or a baking process, we can dry the coated substrate. Dip coating is a very famous coating technique through which we can coat the substrate very uniformly.

Stages of Dip Coating

There are three-stage of the dip-coating methods

1. Immersion

Immersion is the stage in the dip coating in which we immerse the substrate in the tank containing the coating material with constant speed. Our substrate remains fully immersed in the tank for coating. Coating materials start coating on the substrate.

2. Withdrawal

After immersion, withdrawal is the stage in the dip coating. In withdrawal, the substrate is withdrawn at a constant speed to ignore the judders. The withdrawal speed is the factor that influences the thickness of the coating on the substrate. When we increase the speed of the withdrawal of the substrate after immersion the more thickness layer of the coating material is formed on the surface of the substrate

3. Evaporation

When we withdraw the substrate from the tank after immersion the evaporation stage is coming in the dip coating. In this stage, we dry the substrate by baking in this way we thin and uniform layer of the coating material is the deposit on the surface of the substrate

Advantages and disadvantages of the dip coatings:

Dip coating is a very simple coating process. The thickness of the coating material on the substrate is controlled by the viscosity of the coating material and the rate of the withdrawal of the substrate from the immersion tank. Dip coating is a coating

process in which we can coat the different shapes of objects. We can also coat the different sizes of the object in the immersion tank

There are some drawbacks to the dip coating. mostly the thickness of the layer which is coated on the substrate varies from top to bottom due to the wedge effect .so due to this effect most of the time we have unequal coating deposit on the surface of the substrate

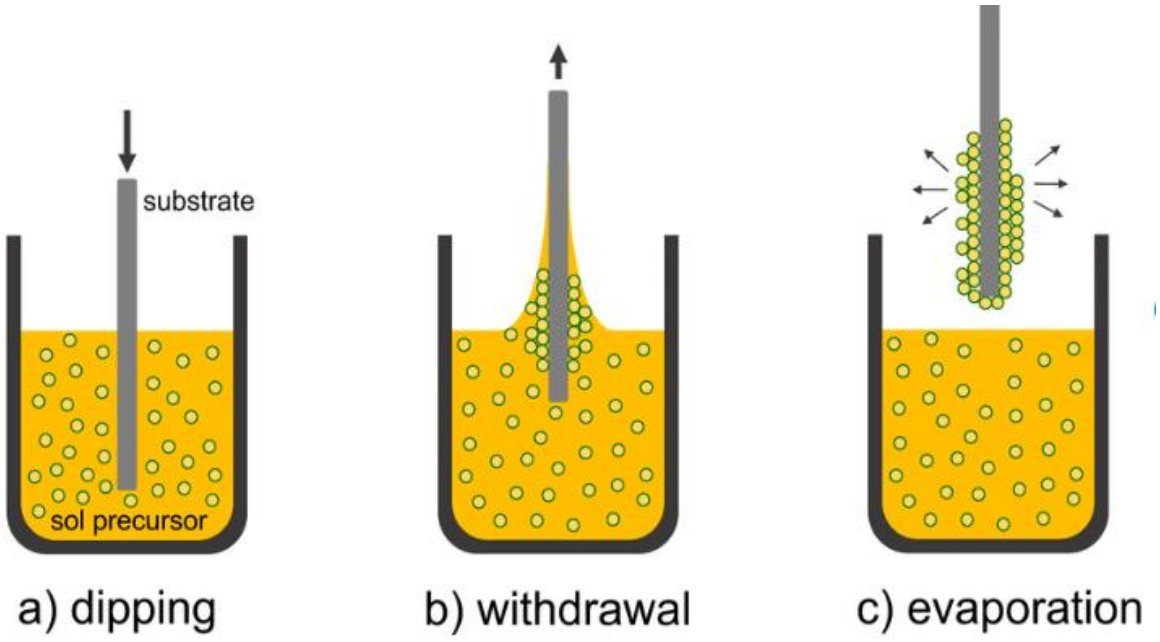


Figure 2.2 Schematic of dip-coating method

2.2.2 Electros pining coating:

Electros pining coating is a coating process in which material is coated on the surface of the substrate by electrohydrodynamics. In the electrohydrodynamics process drop in the jet is electrified with the help of an electric field applied by the high voltage power supply. Electrospinningcoating is a very simple coating method that can be easily designed in the lab. The basic components in electrospinning involve a high voltage power supply, syringe pump, spinneret, and conductive collector. when can use the both power supply AC source and DC source for the electrospinning. When the liquid is extruded from the spinneret the drops are formed. These drops are electrified. The electrostatic aversion among the surface charges that include a similar sign distorts the drop into a Taylor cone, from which a charged fly is catapulted. The stream at first reaches out in an orderly fashion and

afterward goes through enthusiastic whipping movements due to bowing insecurities. As the stream is extended into better breadths, it cements rapidly, prompting the testimony of strong fibers on the grounded gatherer.

Steps in the Electrospinning process:

In electrospinning, there are four main steps

1. Charging of the liquid droplet
2. Extension of the charged jet on a straight line
3. Thinning of the jet due to the presence of the electric field
4. Solidification and collection of the jet as solid fiber on a grounded collector

Advantages and disadvantaged of the Electrospinning

The main advantage of the electros pining technique is to coat a very thin fiber to order of a few nanometers with a large surface area. After coating, we have high mechanical properties from the Electrospinning process.

There is some limited control of pore structure which is a significant disadvantage of electrospinning. The pore size of electro spin scaffolds is dependent on the fiber diameter, with smaller diameter fibers leading to smaller average pore sizes, which in turn leads to decreased cellular infiltration

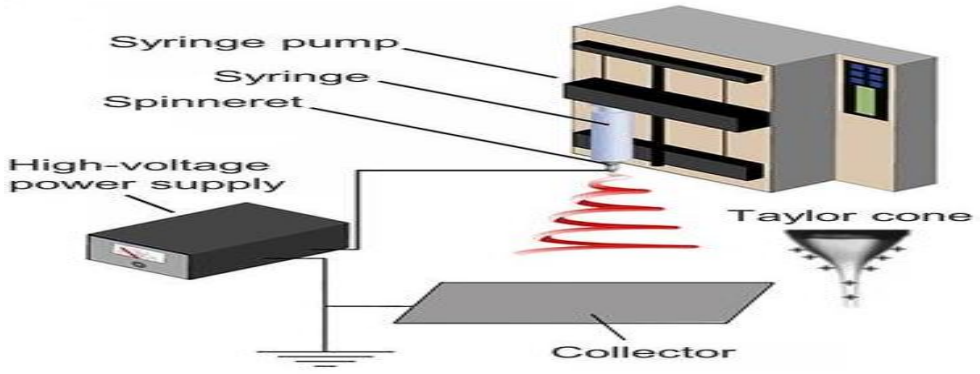


Figure 2.3 Schematic of electrospinning methods

2.3 Comparison between EPD, DIP coating, and Electros pining coating:

Table 2.1 comparison between EPD, Dip coating, and Electrospinning

Types of coating	**Thickness**	**Advantages**	**Disadvantages**
Electrophoretic deposition (EPD)	0.1 to 2.0mm	Uniform coating thickness, rapid deposition,coat complex substance	Required high sintering temperature, high cost of precursors
Dip coating	20 nm up to 50 µm	the thickness of the layer by controlling the viscosity of coating material speed of withdrawal of substrate	Unequal coating layer due to wedge effect from top to bottom of the substrate
Electrospinning	93.18 µm to 619.22 µm	very thin fibers to the order of few nanometers with large surface areas	poor cell infiltration and migration as a result of the close packing of scaffold fibers

2.4: Methodology for wound healing

Table 2.2 Different types of materials and coating methods for the surgical suture

Types of non-absorbable Suture material	**Materials to make suture conductive**	**Types of coating to coat suture**	**Materials that can be coated for healings**	**Their importance in the wound healing**
Natural Silk	Gold coating for suture	Dip coating	Moringa olifera Leaf	protect your skin from a skin infection, inflammation and even treats burn scars
Synthetic Polyamide (nylon)	Sliver coating to make suture conductor	Electrophoretic deposition	Turmeric antioxidant, anti-viral, anti-bacterial, anti-fungal, anti-carcinogenic, anti-mutagenic and anti-inflammatory	For copper, it promotes angiogenesis and skin ECM formation and stabilization
Synthetic polyester (Dacron)	Copper coating to make sutures conductors	Possibly CVD Chemical vapor deposition PVDPhysical vapor deposition	Mango ginger AntipyreticAmba Haldi is Anti-Bacterial, Anti-Fungal, And Anti-Oxidant.	itching in the skin wounds It helps in treating skin problems.
Synthetic polypropylene (prolene)	Cross-linking polymers	Electrospinning	Gandhak Rasayan Detoxified Sulfur	Antibacterial, antiviral, and antimicrobial medicine.

2.5 Polymerization of Aniline on non-absorbable silk braided suture

2.5.1 Materials

Silk braided non-absorbable surgical silk suturesare used as a substrate. Aniline is a monomer. ammonium persulphate (APS) is used as an oxidant. Concentrated Hydrochloric acid is used as a dopant

2.5.2 Experiment of conductive silk braided suture

Normally this experiment required a very large amount of solution to make silk suture conductive. Nowadays we improve a method to get an optimum condition for the experiments. Firstly take a silk nonabsorbable surgical suture unwound from the cover and apply little tension with the help of a tensioner. At point (3) we have a tank containing the mixed solution of aniline monomer and hydrochloric acid as a dopant acid. We immersed the silk suture in a tank and then removed and squeezed it. Silk sutures absorb aniline and HCL acid. When we pass the silk suture through the roller press mixture solution is immersed on the surface of the silk suture. At point (6) we have an (APS) ammonium persulphate as an oxidizing agent, aniline as a monomer, and HCL as a dopant acid. After passing the silk suture from tank 2. The mixedsolution is immersed on the surface of the silk suture. After24-hour aniline is converted into the PANI polyaniline due to polymerization.

The concentration of HCL which is a doping acid and the aniline monomer is 3.6 mol/L. Ammonium persulphate which is used as an oxidizing agent has a 1.5 g. The amount of HCL is 0.5 ml and aniline is 5 ml which is used in the experiment. The color of the silk suture is depended on the concentration of the ammonium persulphate. By increasing the concentration of the ammonium persulphate (APS) the darker the silk suture is obtained.

Due to the polymerization of aniline monomer into polyaniline on the surface of the silk suture. We obtained high mechanical, thermal, and conductive properties on the silk suture which is used as a substrate for the coating of the Moringa with the help of electrophoretic deposition (EPD).[12]

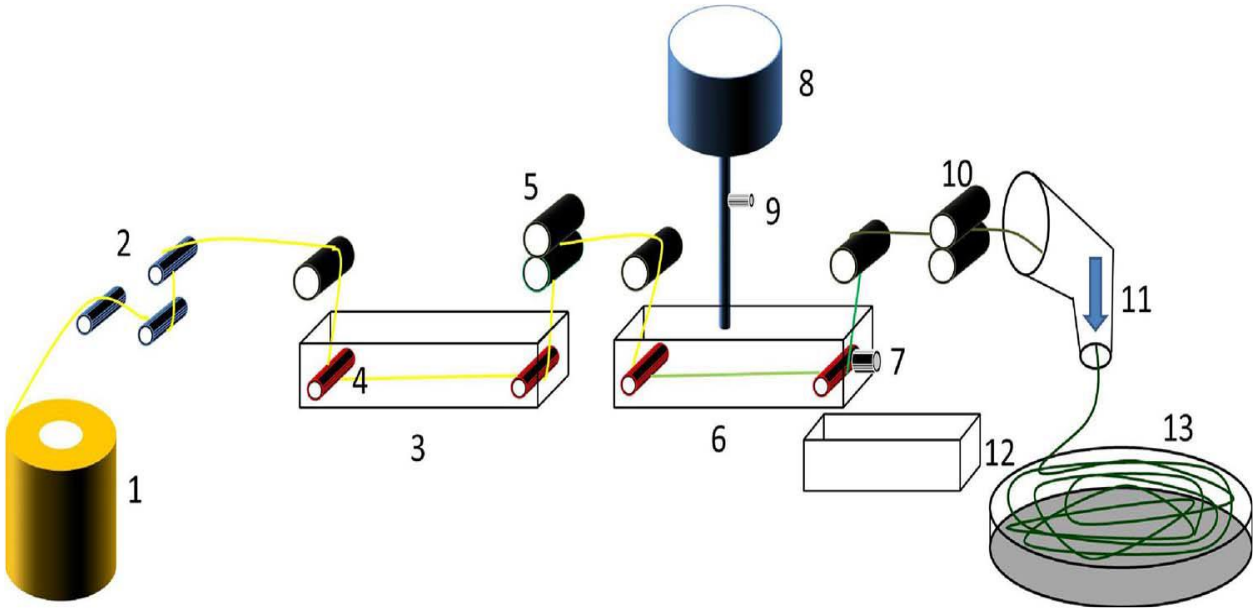
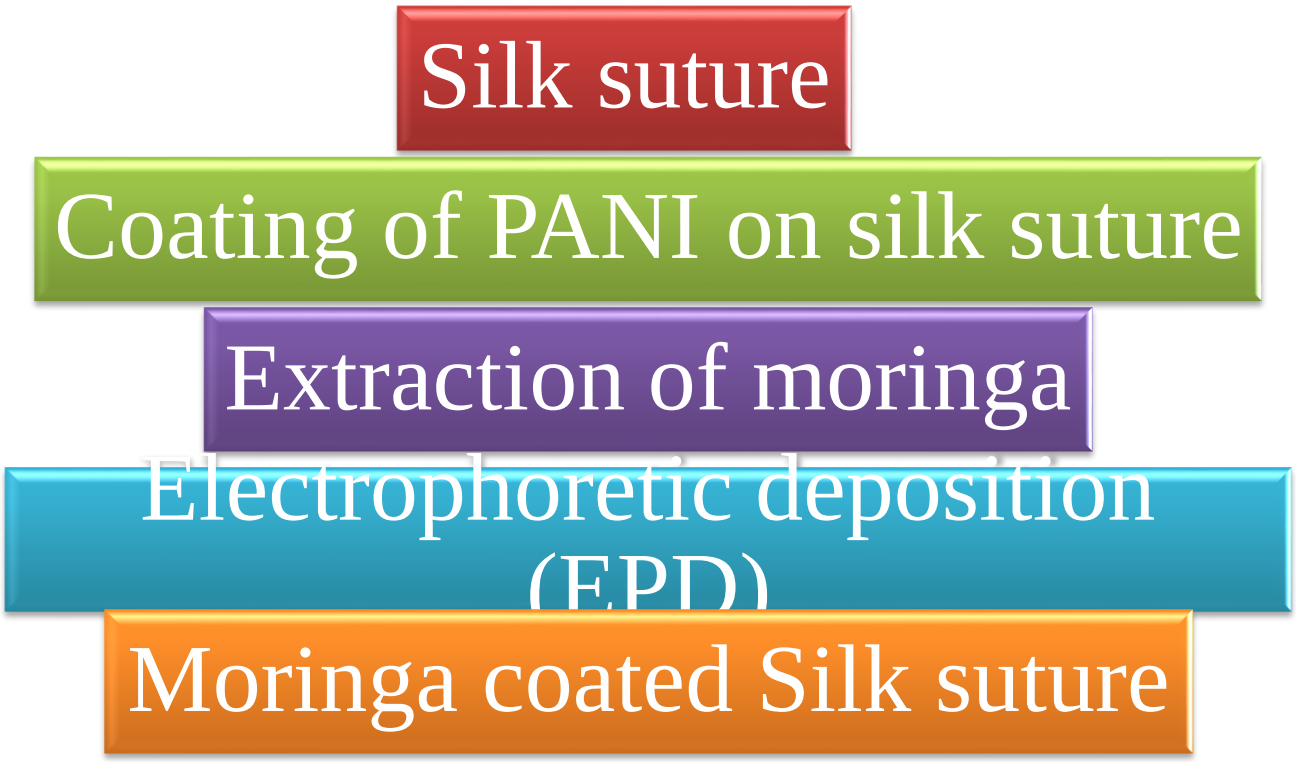


Figure 2.4 Schematic of making silk suture conductive by the polymerization of aniline monomer



2.6 Moringa coating on the silk suture with the help of ElectrophoreticDeposition

EPD has a variety of ways for the fabrication of the different traditional structures into advanced-level materials. EPD can coat a 1 mm thin film on the substrate which is a high-impact coating process. With the help of EPD, we can coat different shapes of the material with very simple apparatus and equipment.

EPD means electrophoresis deposition. It is a very important deposition method for good and effective different materials coatings. In this method charged particles in a liquid or a colloidal solution are moving due to an electric field and deposit on a conductive substrate that is oppositely charged. We can do a highly compact coating by using the EPD coating method. EPD has a very versatile application. EPD is less cost-effective as well as short processing time. EPD process has a simple apparatus and equipment. With the help of EPD, we can do the facile modification as well as coat the different shapes of the material.

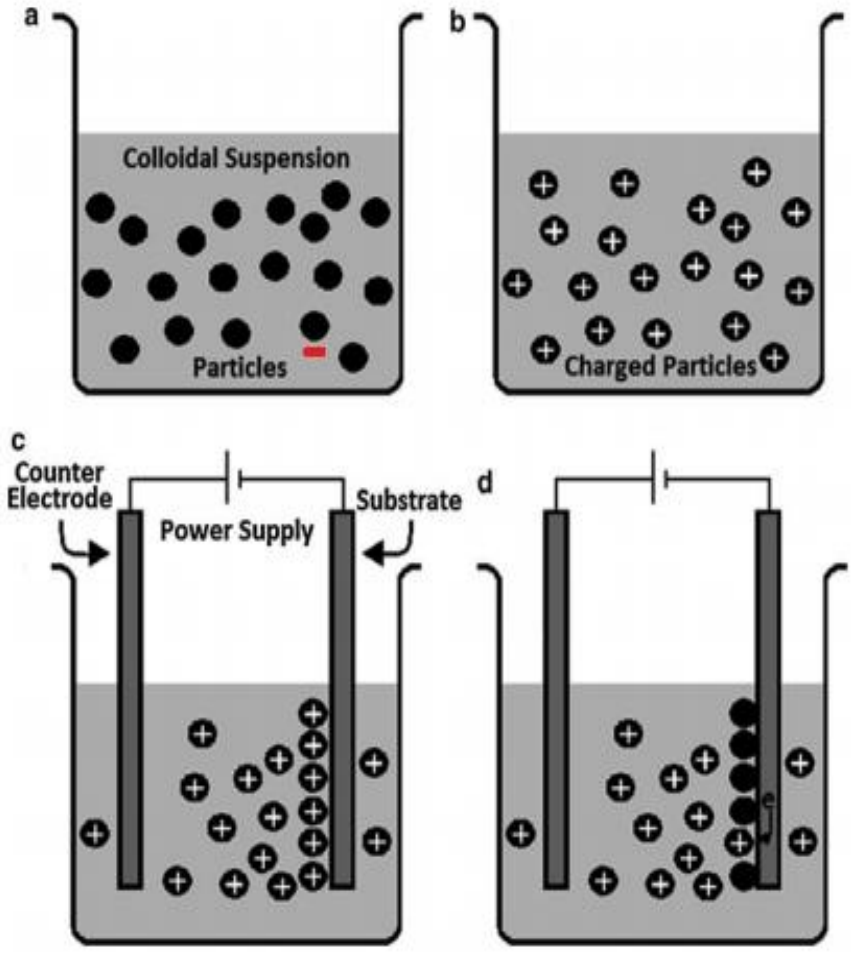
AC and DC both are used in the process of EPD but most of the common DC supplier is used for the EPD process. 1in EPD we can control the thickness and morphology of the material 2in 1970 EPD process is discovered by Bose and notice the movement of the clay particles due to the applied electric field. With the help of the EPD in 1927,Harsanyi coated the thorium and tungsten on the platinum cathode for electron tube application 3back in 1950 scientists used the EPD process to coat aluminum trioxide on cathode for the heater in vacuum tubes.

Electrophoretic depositions have three main stages. Electrodes (anode and substrate on the cathode), colloidal suspension, dc supplier (Ac and Dc).

Many mechanisms are proposed for the optimum results of EPD still there are many characteristics of the EPD technique which make it unique and different from the similar charged deposition-based techniques. In fig 1.4 (a) A suspension which has a colloidal particle which is freely moved in the solvent suspension (b) with the help of anode we charged the particles electrochemical equilibrium occurs in the suspension

(c) when we apply the counter electrode our charged colloidal particles are moved towards the substrate which acts like a cathode (d) charged particles are deposited on the conductive substrate which is a cathode electrode

EPD technique is a very unique process of deposition because in EPD the solid charged particles are moving in a liquid medium due to the electrostatic force. The results of the EPD highly depend on the stability of the suspension and the charge on the surface of the materials [13]



1 Four steps of EPD; (**a**) dispersion, (**b**) electrochemical charging, (**c**) electrophoresis and (**d**) deposition

Figure 2.5 Schematic of process of electrophoretic deposition (EPD)

Take Moringa olifera powder from the preserved container. Measure 4 grams of the Moringa olifera powder by digital balance. Put 4 grams of Moringa powder into the beaker of 100 ml. Add 10 ml distilled water by using the pipette. Then add 3 ml acetic acid with the help of a pipette into the beaker containing Moringa olifera powder and distilled water. Now put the beaker on the magnetic stirrer for 30 minutes. after stirring add 37 ml ethanol which is the main solvent for the suspension which is used for the EPD process. Put the suspension in a sonication bath for 30 minutes. After sonication again put the beaker on the magnetic stirrer for 60 minutes. Now check the value of PH of the suspension with the help of the ph meter.The ph value should be around 3 to make a very fine suspension. An ideal value of ph of the suspension for the EPD is 3. When we make a very fine suspension then charged particle is ready to deposit easily on the substrate. After this experiment, our suspension is ready to deposit charged particles on the conductive substrate. We make our silk braided non-absorbable suture conductive by the polymerization of the aniline on the surface of the silk suture. Our sample is conductive due to PANI polyaniline on the surface of the silk braidednon-absorbable suture. In our suspension, we have two electrodes in one is an anode while the other electrode is a cathode. There is a spacer between anode and cathode in the suspension which is highly charged. These electrodes are connected with the DC suppliers. We have SS stainless steel electrodes in the suspension. We attached the sample which is a silk braided non-absorbable suture at the cathode electrode. We apply the voltage of 20 v and the current of 0.08 amperes for 5 minutes. We can see the deposition of the positive charged solid particle of Moringa olifera on the negatively charged cathode which is our sample silk braided non-absorbable suture. After 5 minutes we remove the sample from the cathode electrode and place it in the air for drying. When the sample is dried we can see the coating of the Moringa olifera on the substrate, a very firm and very protective coating is on the silk non-braided sutures. After repetition of the experiments, we get an optimum condition of DC voltage and time for applying on the sample for better coating. we take different compositions of Moringa powder in suspension. We take 3g, 4g. 5g,6g. 4g Moringa powder compositions in the suspension show the very unique results in the coating with the help of EPD. [14]

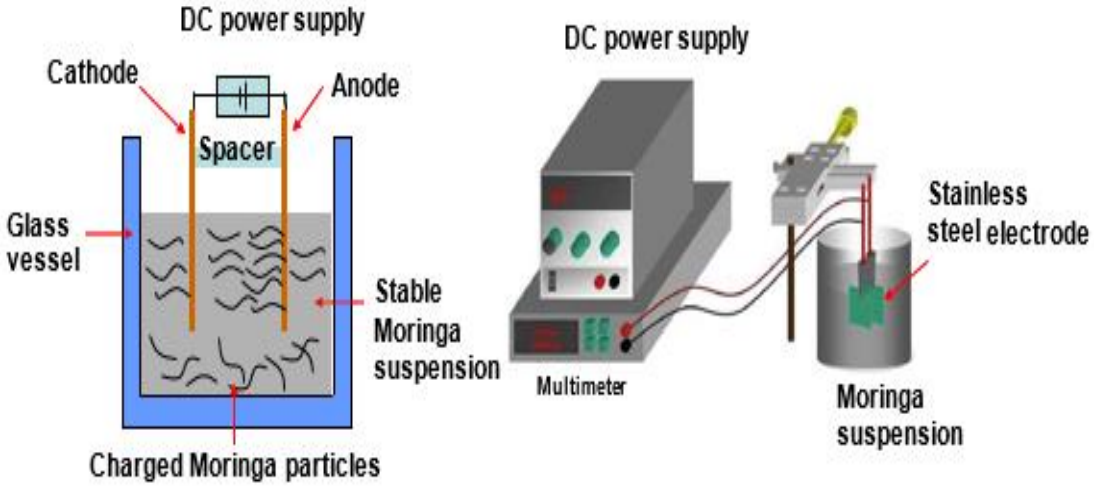


Figure 2.6 Schematic of electrophoretic deposition (EPD) of Moringa on silk surgical suture

Chapter:3

Characterization of Moringa coated silk suture

3.1 Scanning Electron Microscopy (SEM) of Moringa coated silk sutures

(SEM) scanning electron microscopy is used to characterize the morphology of the surface of the materials. In our project, we use SEM (JSM-6510-JEOL)to characterize the silk braided nonabsorbable suture with or without a coating of the Moringa Olifera. Firstly we prepare the sample silk braided nonabsorbable suture for the characterization of the scanning electron microscopy. For the preparation of the sample for SEM. our silk braided nonabsorbable suture is coated with gold of 5 nm thickness by using gold sputter in a vacuum. JEOL (SEM) took images at an excitation voltage of 20 kV

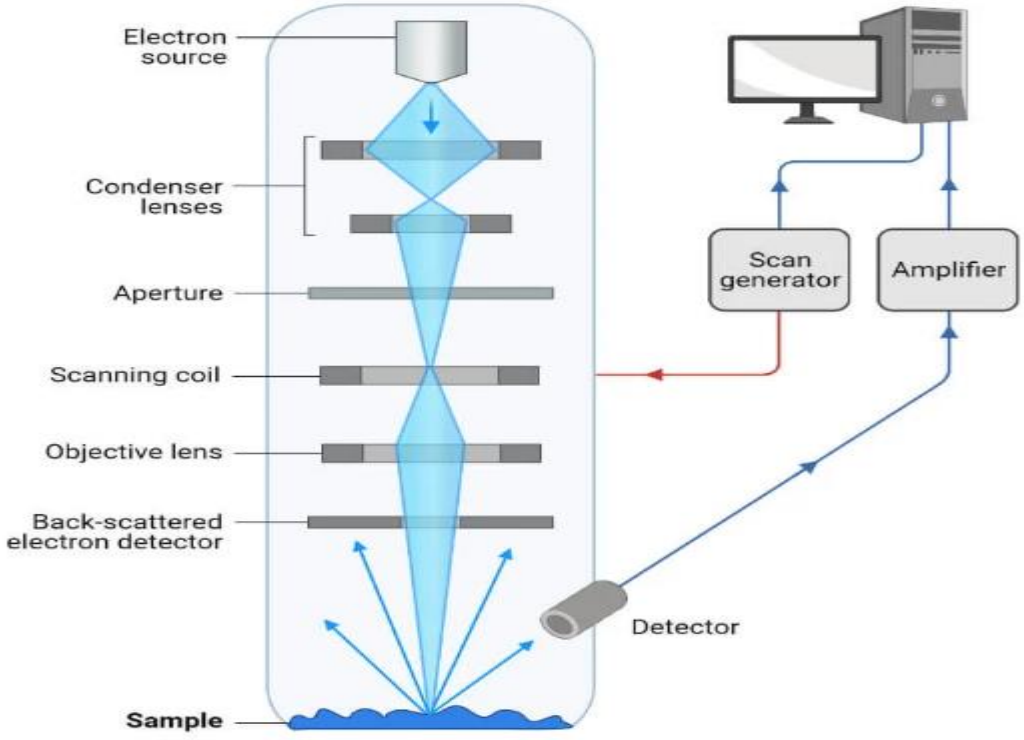


Figure 3. 1 Schematic of scanning electron microscopy

3.2 Fourier transforms infrared (FTIR)

Fourier transforms infrared radiation (FTIR) spectrum is used to identify the different functional groups from FTIR we have a fingerprint region through which we can calculate the functional groups which are attached to the materials. The absorption range for the Moringa olifera leaves is from 3387.33 cm to 593. 50 cm.

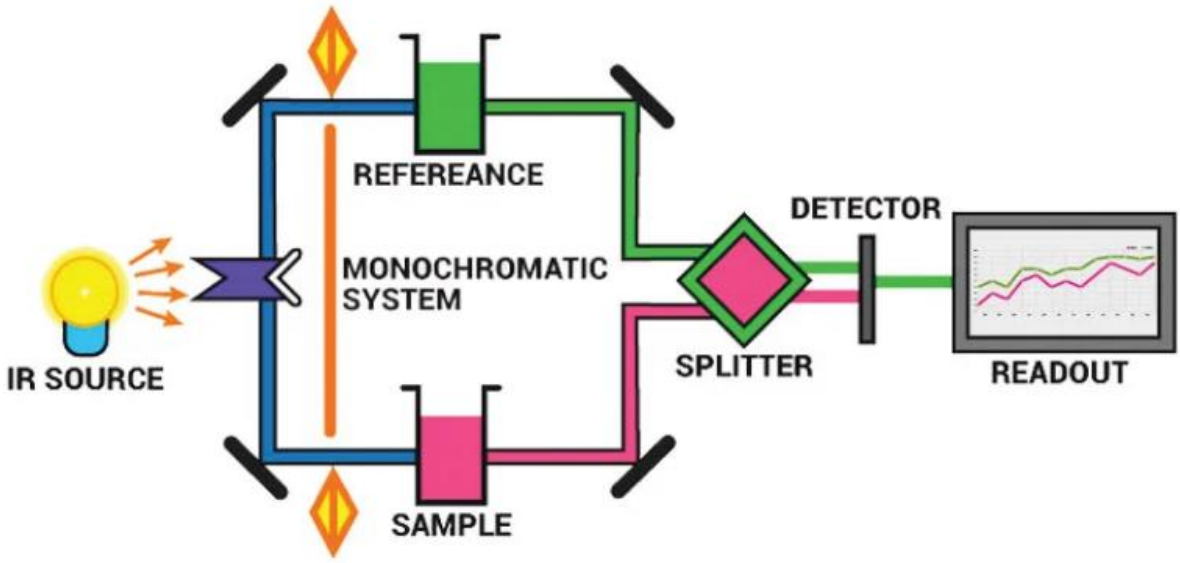


Figure 3. 2 Schematic of Fourier transformation infrared

3.3 Mechanical properties of silk sutures

We can find the mechanical properties of the silk braided nonabsorbable suture with the help of a *pull test* by the UTM (universal testing machine SHIMAD2U 20KN). For the pull test, we take a sample of silk sutures approximately 2.5". Our silk braided nonabsorbable sutures with or without coating are kept in an optimum environment. We perform a *pull test* at room temperature.UTM (Universal Testing Machine) is used to measure the tensile strength of the silk braided nonabsorbable sutures. The gauge length for the *pull test* is 1". In UTM silk sutures were pulled at 10 mm/ min for the tensile test until the complete fracture point occurs. In UTM we use the 100 N load cells for the

measurement of force and displacement graph. Force and displacement curve is obtained from the measurements of the pull test from UTM. The tensile test is used to measure the max load, stiffness, and work to failure.

Figure 3. 3 Diagram of universal tensile testing machine

3.4 Moisture retention of silk nonabsorbable surgical suture

To measure the moister retention we use the drying oven. Firstly we take a Moringa coated silk braided nonabsorbable suture placed in digital balance to measure the initial of the sample which is w1.we place our sample in a drying oven at 40 c for 6 hours. After drying again put the sample in digital balance to measure the final weight which is w2. With the help of the given formula, we can check the moisture retention of Moringa coated silk nonabsorbable sutures.

Moisture retention = (w2/w1*100)

W1 is the initial weight of the silk braided suture 4.8mg

W2 is the final weight of the silk braided suture 4.2mg

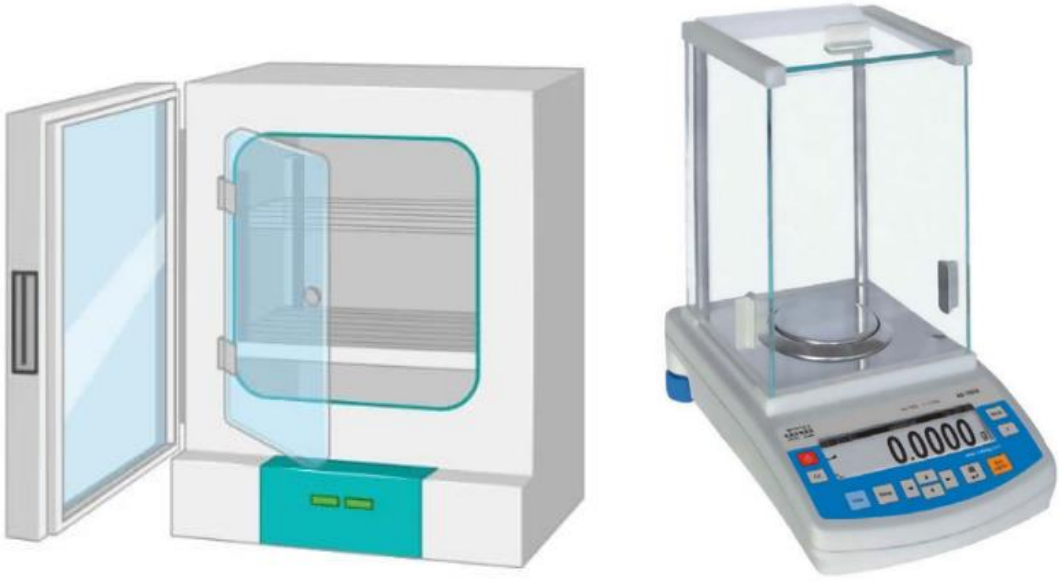


Figure 3. 4 Diagram of drying oven and digital balance

3.5 Antibacterial testing (E coli TEST)

We use antibacterial testing to measure the anti-microbial activity of the Moringa coated silk nonabsorbable suture. When we perform an antibacterial test to check the anti-microbial activity an inhibition zone is formed which shows the efficiency of the anti-microbial activity of our Moringa coated silk nonabsorbable silk suture. Moring coated silk suture is evaluated against the E COLI strain. Firstly we culture the E coli bacteria over the night in a drying oven. we pour the media on the autoclaved plates and then spread the culture bacteria. After spreading the E coli bacteria we put the Moringa coated or uncoated silk nonabsorbable suture on the fresh E coli autoclaved plates.

For the incubation, we place the autoclaved plates in the drying oven at 37 c overnight. After 24 hours we check the results of the antibacterial drug on a silk nonabsorbable suture. An inhibition zone is formed against the bacteria which shows the anti-microbial property of the Moringa coated silk suture.

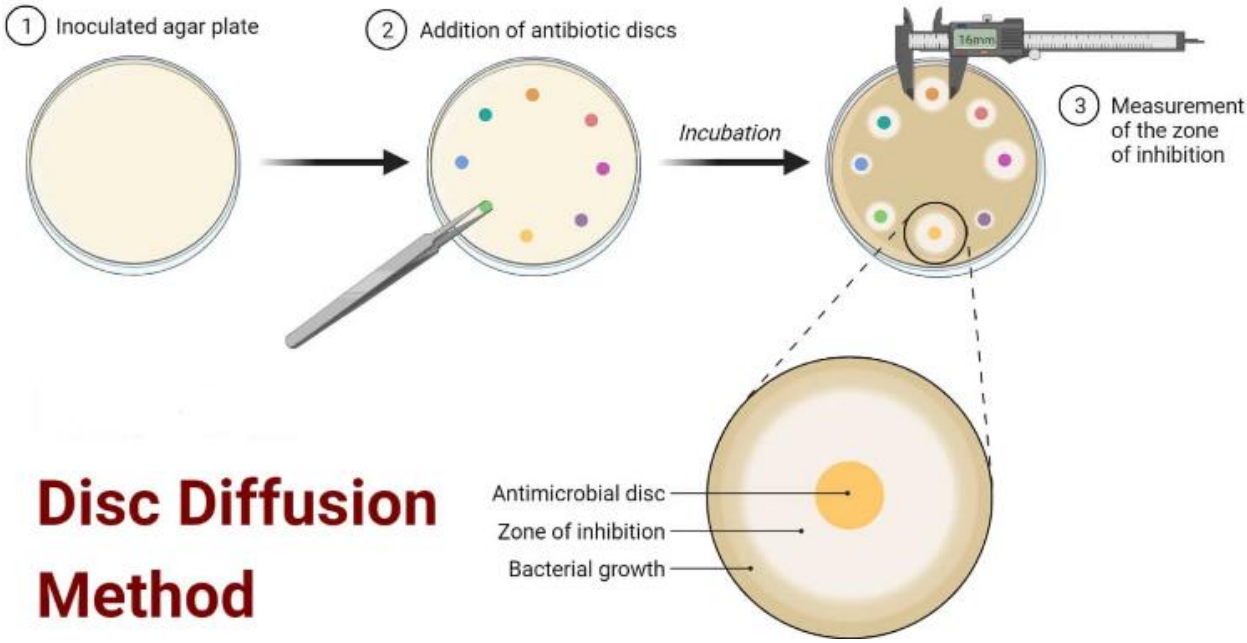


Figure 3. 5 Schematic of Anti-bacterial testing of E coli testing

3.6 Drug release test of Moringa and chitosan on the surgical suture

We used the drug release test to check the behavior of our drug release into the blood of the human body. Firstly, take a 50 ml wale plastic tube then add 40 ml SBP solution (simulated body fluid). SBP is a solution that is close to the human blood plasma and is kept at a standard condition of Ph value and temperature. To check the efficiency of the Moringa release in a body firstly we make a pellet of the moringa. Then check the optical density of the moringa pellet. Now place the pellet of moringa in an SBP solution for 6 hours at 37.5 c temperature in a shaking incubator. After 6 hours take a 1 ml solution in a test tube. Again check the optical density of the solution. Add 1 ml fresh moringa into the solution. Now take 1 ml solution after the 12 hours of incubation at 37.5c temperature. Check the optical density of the 1 ml solution. We repeat this experiment by adding 6 hours to the previous hours.

We can check the deposition of the moringa and chitosan on the surgical sutures. By measuring the weight before and after coating on the surgical sutures. In this way, we can check the quantity of the coating on the surgical sutures

Chapter:4

Results and discussions

Digital images of the silk suture with or without coating

Aniline is converted into PANI by the polymerization of Aniline. The coating of the PANI can be seen on the surface of the silk braided non absorbable suture with the naked eye. We can also see the surface of the coating with help of high resolutions digital camera. Fig 4.1 our scale bar is 0.2 inches. Our digital camera images show that our coating is firm and protective on the silk suture as compared to the uncoated silk suture. When we immersed our coated silk suture in the water of PBS solution. After drying our coating is more brittle on the surface of the silk suture.

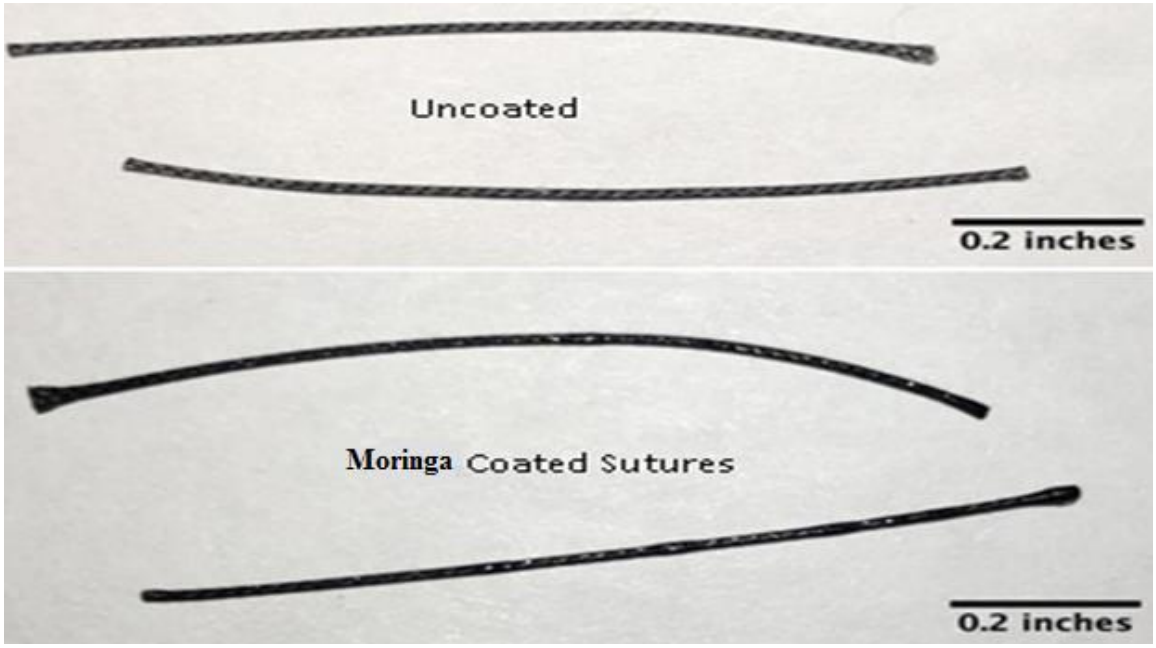


Fig 4.1 camera images of silk braided non absorbable and PANI coated silk braided non absorbable sutures 0.2 inches is the scale bar here.

4.1 Characterization of scanning electron microscopy for the morphology of the Moringa coated silk braided non absorbable suture

Scanning electron microscopy images fig 4.2 shows that the silk braided non absorbable sutures are completely coated with the Moringa. Fig 4.2 (a,c,e) the uncoated silk braided non absorbable suture while Fig 4.2 (b,d,f) shows the Moringa coated non absorbable sutures. From the coated images of the silk braided non absorbable suture, we get an idea that coated sutures are uniform.

For the scanning electron imaging, we prepare a sample in a vacuum that converts our Moringa-coated suture into the dry sample. Therefore these little micro-cracks are due to present in the SEM images due to stresses experienced during drying .our coated sample is uniform before drying.

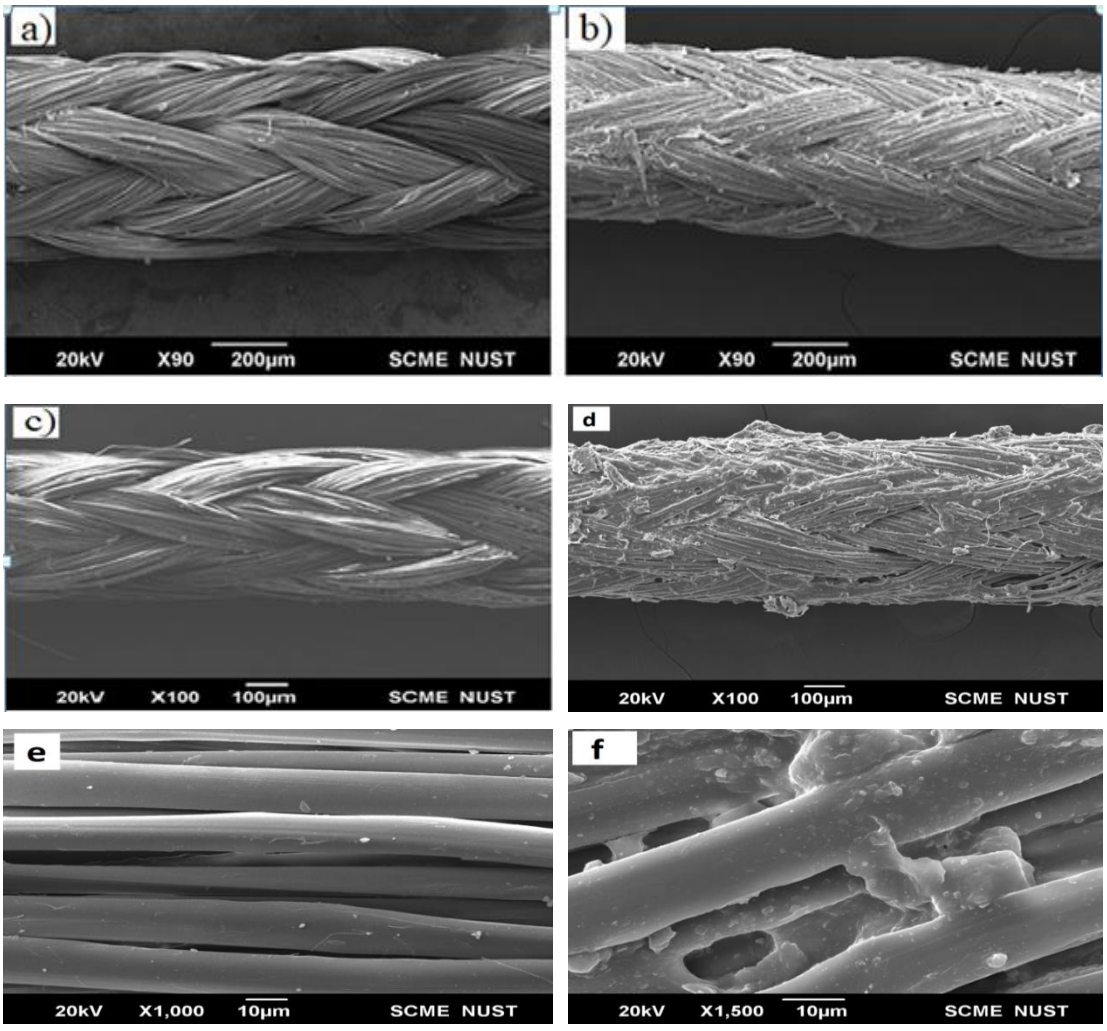


Fig 4.2 scanning electron microscopy images of silk braided non absorbable sutures before and after Moringa coatings. (a,c,e) before coating images (b,d,f) after Moringa coating images .

4.2 Fourier transforms infrared

4.2.1 Fourier transforms infrared of Moringa

The Fourier transforms infrared spectrum shows the absorption range from 3421.51 cm^{-1} to 564.93 cm^{-1} Fig (4.2).in the spectrum the peak at 3421.51 cm^{-1} shows the presence of the (OH, N-H) group. This shows the presence of phenol and flavonoid. The peak at 2919.60 cm^{-1} shows the presence of the Alkanes group (C-H). There is a very long and sharp peak at 1635.64 cm^{-1} which indicates the presence of the amines groups (N-H). The peak at 1437.01 cm^{-1} shows the presence of the aromatic amines (C-H). Another very sharp peak is shown at 1031.81 cm^{-1} that show the presence of aliphatic amines (C-H). Peak 564.93 cm^{-1} shows the presence of the alkyl halides (C-BR).FTIR spectroscopy of the Moringa Olifera Leaves shows that the functional groups of alcohol hydroxyl alkanes amines aliphatic amine aromatic amines alkyl halides.

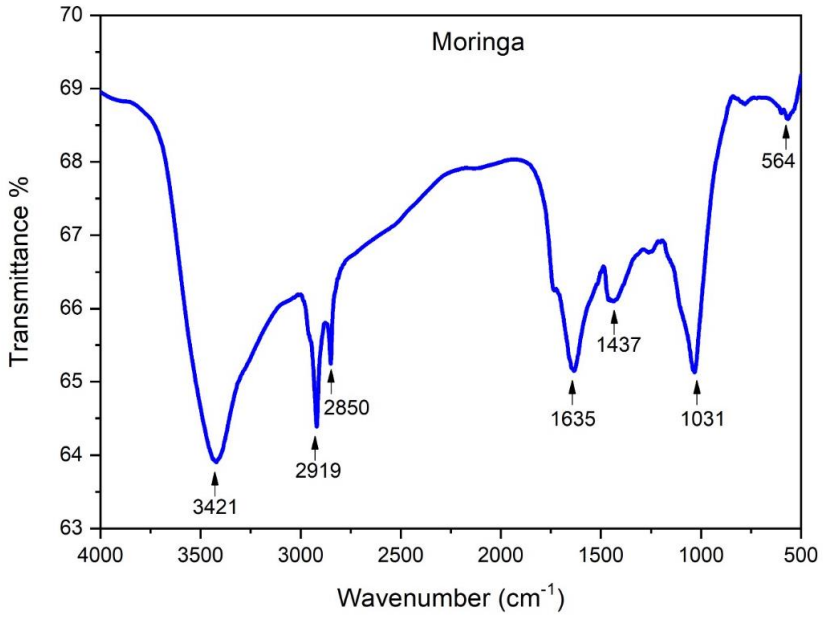


Fig 4.3 shows the FTIR spectrum analysis of Moringaolifera leaves

Fourier transforms infrared of PANI:

The Fourier transforms infrared spectrum shows the absorption range from 2918.11 cm^{-1} to 605.48 cm^{-1} Fig (4.2). In the FTIR of PANI, this is no peak between 3100 cm^{-1} to 3000 cm^{-1} which shows that there are no C-H stretching vibrations on the benzoic ring. The peaks which are observed at the 2918.11 cm^{-1} regions show the symmetrical C-H Stretching vibrations. The peak 1608.97 cm^{-1} represents the C=H stretching mode for the amine. The region between 1640 cm^{-1} to 1560 cm^{-1} has no peaks which means no shear vibration of C-N. The peak at 1024.77 cm^{-1} shows the C-N stretching mode for the benzoic ring. Peak 735.15 cm^{-1} represents the WAG VIBRATION OF N-H Bond.

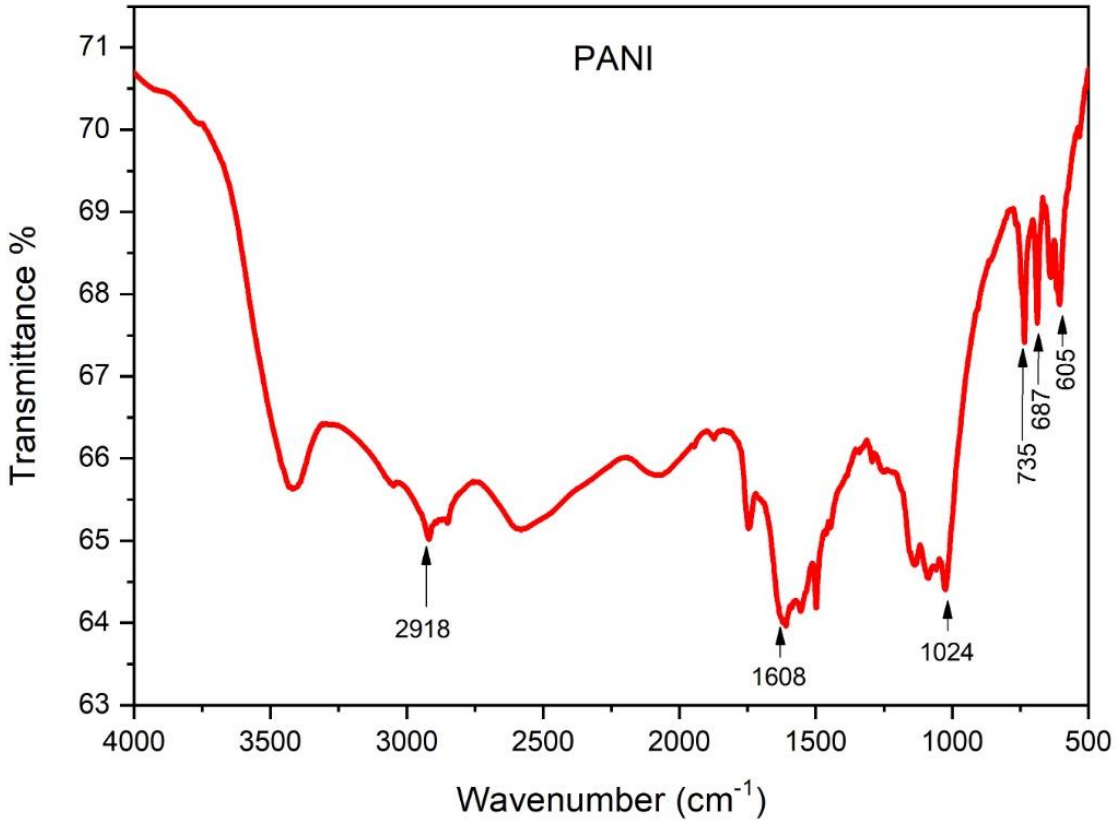


Fig 4.4 shows the FTIR spectrum analysis of PANI (polyaniline)

4.2.2 Fourier transforms infrared of chitosan

The Fourier transforms infrared spectrum of chitosan shows the absorption range from 3427.96 cm^{-1} to 573.91 cm^{-1} Fig (4.2).in the spectrum the peak at 3427.96 cm^{-1} shows the presence of the (OH, N-H) group. The peak at 2874.35 cm^{-1} shows the presence of a C-H stretch bond. Peak 1652.14 cm^{-1} shows the presence of amide 1. The peak at 1598.99 cm^{-1} shows the presence of N-H bending from amine and amine II. The peak 1422.72 cm^{-1} shows the presence of CH2 bending .peak 1382.80 cm^{-1} shows those CH3 deformations. Peak 1156.31 cm^{-1} shows an anti symmetric stretch of C-O-C and C-N stretch. Peak 1031.61 cm^{-1} shows the presence of skeleton vibration of the C-O stretching.

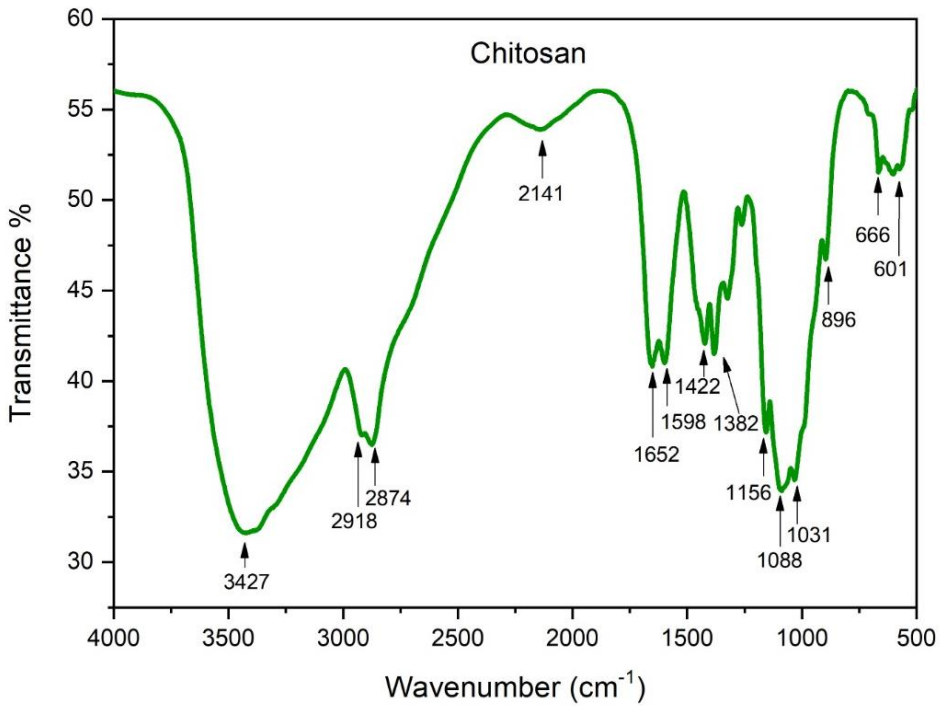


Fig 4.5 shows the FTIR spectrum analysis of chitosan

4.2.3 FTIR spectrum analysis of Silk (black curve), Silk +PANI+ Moringa

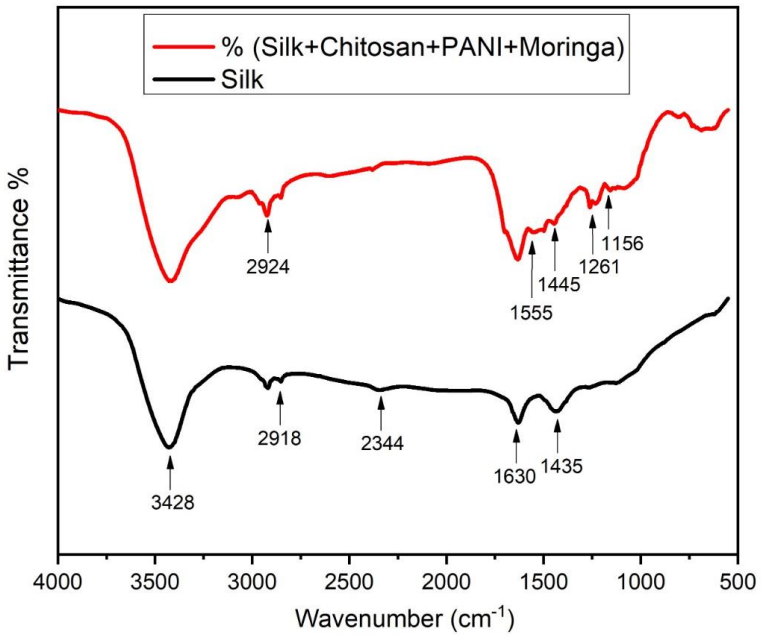


Fig 4.6 FTIR spectrum analysis of Silk (black curve), Silk +PANI+ Moringa (RED)

4.2.4 FTIR spectrum analysis of silk, Pani, Moringa, silk+pani+Moringa

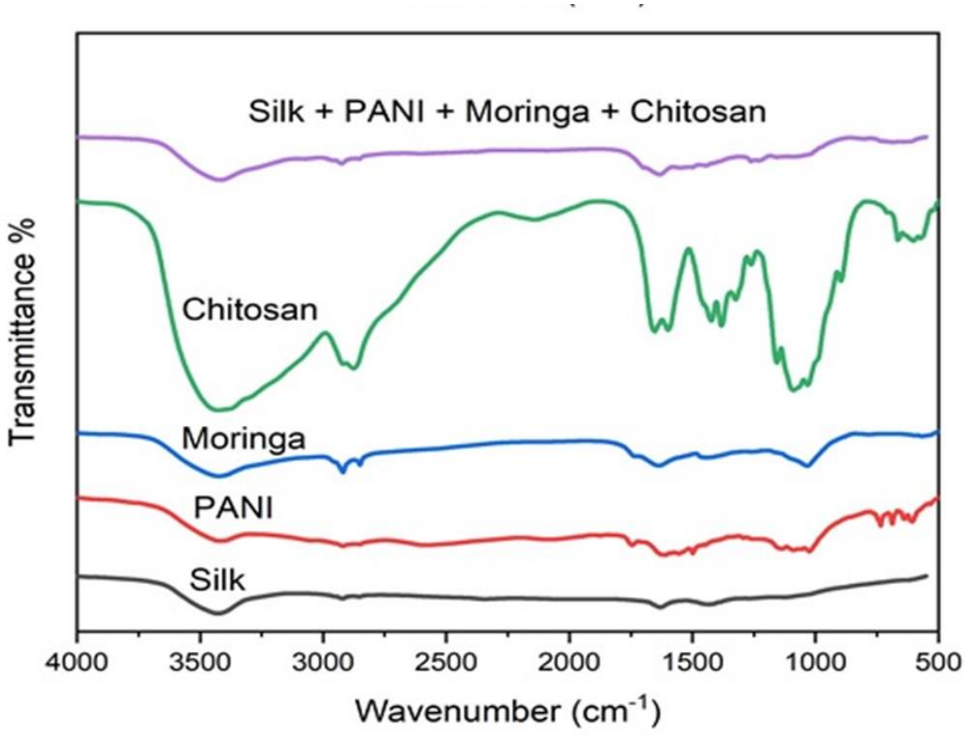


Fig 4.7 FTIR spectrum analysis of silk, Pani, Moringa, silk+pani+Moringa

4.3 mechanical properties of silk sutures

To check the mechanical properties of the silk suture we do a pull test on the universal testing machine. With the help of a pull test, we can calculate the following mechanical properties of the silk braided suture and Moringa coated silk suture. The force-displacement curve obtained from the pull test is used to calculate the several mechanical properties, max loading, work to failure, strain, strain to failure. The curve which is obtained from the normal silk suture and coated silk suture is almost the same as shown in Fig 3.1 one thing the main difference is the maximum displacement is deceased in the Moringa coated suture as compared to normal silk suture. The decrease in the displacement shows an effect on the value of the max load, work to failure, strain to failure for the Moringa coated silk braided nonabsorbable suture. In Moringa coated samples there is a difference concerning normal silk suture in max loading and work to failure. The stiffness value for the coated and uncoated is quite similar no difference between them. By taking the analysis of the pull test curves there is a very significant difference in the mechanical properties which shows that our Moringa coated sample is very acceptable.

4.3.1 UTM of silk suture

When we do a pull test of silk braided non absorbable suture . As the result, we obtained a force (N) and displacement (mm) curve. Force Displacement curve of silk braided nonabsorbable suture during pull test shows that when we apply a force by the universal tensile machine there is a displacement in the silk suture sample which is shown in Fig 3.1.1 by increasing force-displacement is increasing in the curve during the force of 15 N to 45 N shows a linear behavior means the force is directly proportional to the displacement. After the force of 45 N, there is no proportionality between the force and displacement so the curve path is obtained after the force of 55 N cracks start propagating, and at the force of 59 N fracture points occurs.

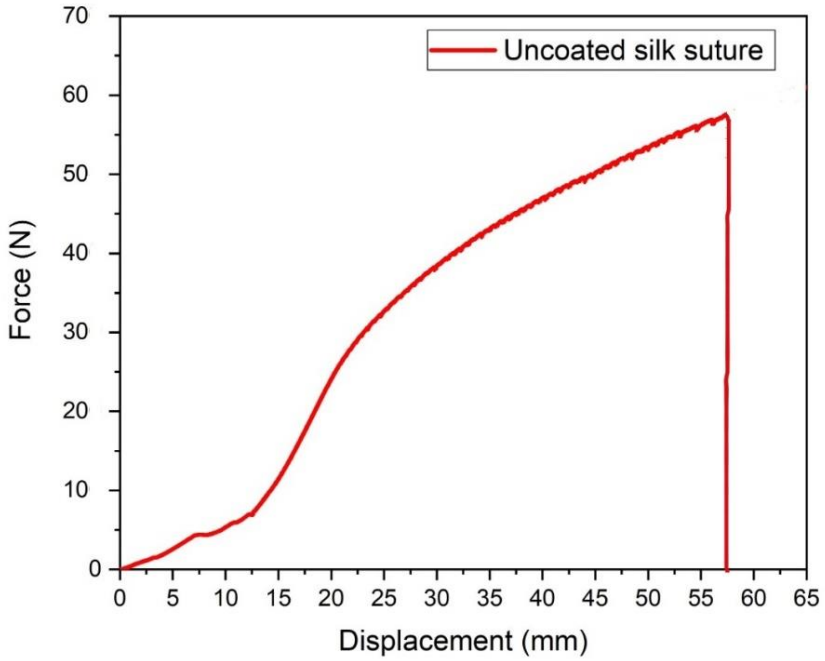


Fig 4.8 Force Displacement curve of silk braided non absorbable suture during pull test

When we placed polyaniline (PANI) coated silk suture in the universal tensile machine (UTM). Force Displacement curve is obtained. From the curve, we can analyze from 20N to 48N shows proportionality between force and displacement. After 48N force, no proportionality exists between force and displacement. When we apply force on the PANI coated silk suture the fracture point is occurred at the displacement of 9.5 mm. There is a decrease in the displacement which is noticeable as compared to normal silk sutures.

4.3.3 UTM of Moringa coated silk suture

When Moringa coated silk suture is placed in the universal testing machine. Force into displacement curve is obtained. From the analysis of the force-displacement curve we get an idea there is a significant decrease in the displacement of our Moringa coated samples. Fracture point has occurred at the displacement of 9 mm. maximum displacement which is noticeable is lies in the Moringa coated silk suture as compared to polyaniline PANI coated silk suture and normal silk suture.

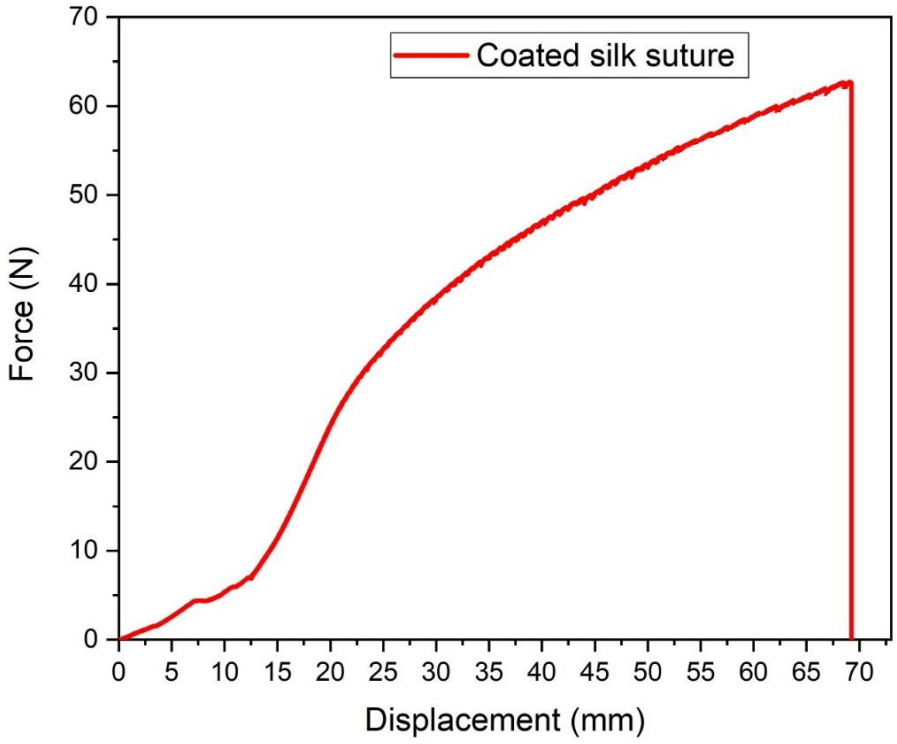


Fig 4.10 Force Displacement curve of Moringa coated silk braided nonabsorbable suture during pull test

Breaking Load coated =69N

Breaking Load uncoated =60N

This result indicates that coating of Moringa and chitosan on the surface of silk suture have positively brought an improvement in its mechanical properties. The polymeric molecules of silk fibers are reinforced by very fine sized Moringa, which probably has acted as cross linking agent or filler increasing the resistance of coated fibers under pulling load. The micro-structural evidence for the same is contemplated from the SEM images

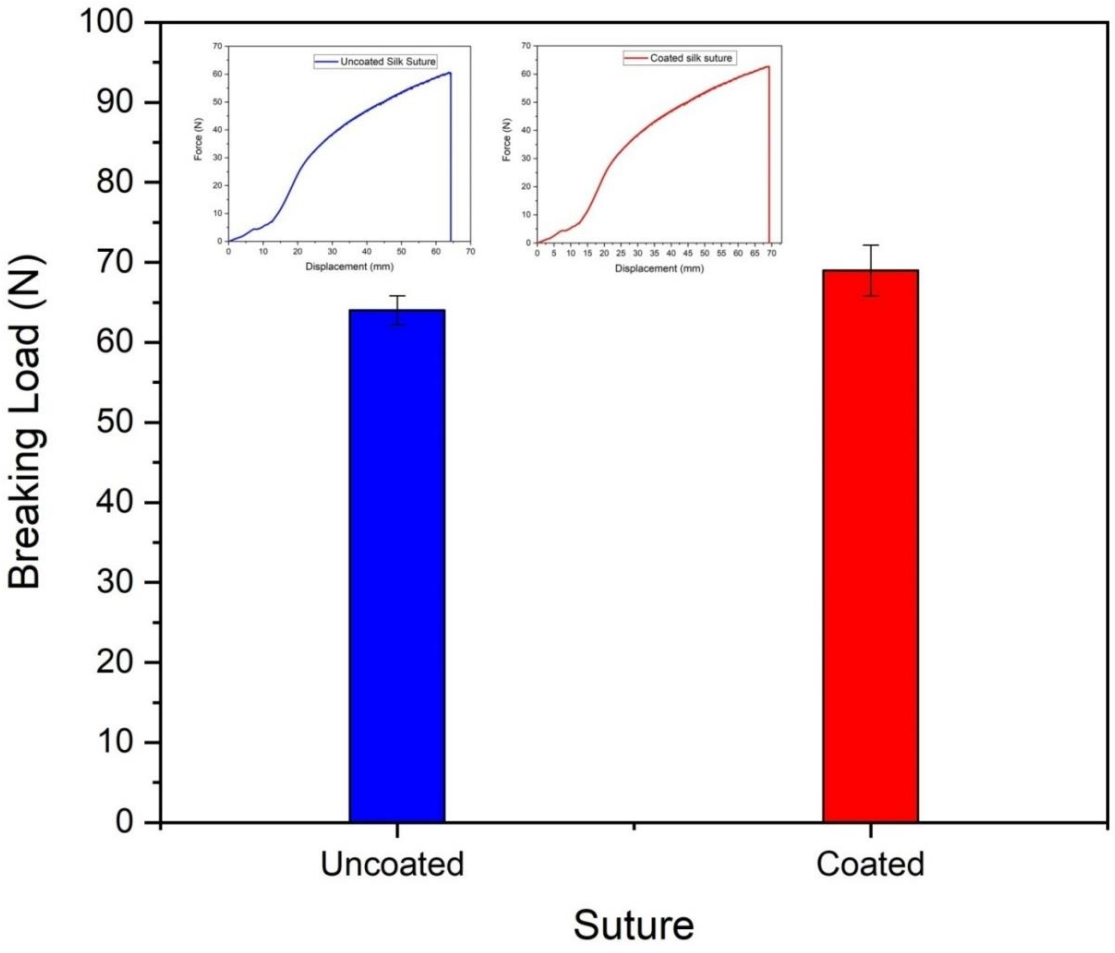


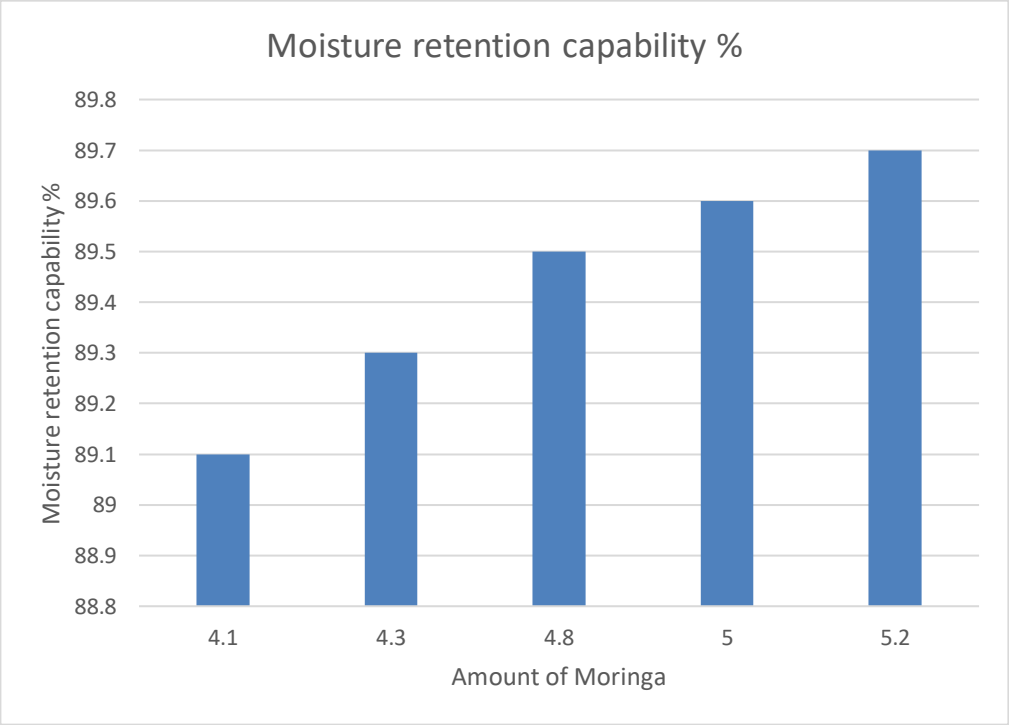
Fig 4.10 Comparison of Force Displacement curve of coated and uncoated silk braided non absorbable suture during pull test

4.4 moisture retention of silk non absorbable surgical suture

Silk braided non absorbable sutures play a very important role in the healing of the wound. When we stitched the infection site through silk sutures . Our Chatison based Moringa plays a very important role in the healing of the wound. Moringa coating on silk sutures enhances the tissue regeneration process on the infection site. One very important factor is moisture retention of the surgical suture is during the stitching process. We do a moisture retention test to check the moisture level on the silk suture. Before coating and after coating there is a difference in the weight of the sample. We dry the samples in a

drying oven for 6 hours at 40 C. after drying the moisture is removed from the Moringa coated silk suture sample so the weight after the drying decreases. With the help of the difference in weight, we can calculate the moisture retention level.W1 is the initial weight of the silk braided suture = 4.8mg.W2 is the final weight of the silk braided suture = 4.3 mg

Moisture retention = (w2/w1*100)



Amount of Moringa and MRC (Moisture Retention Capability percentage) of coated silk braided non absorbable suture

4.5 Antibacterial testing (E coli TEST)

4.5.1 E coli test for normal silk

4.5.2 E coli test for Moringa coated silk suture

To check the antimicrobial activity, we placed our Moringa coated silk braided nonabsorbable suture against the E Coli. An inhibition zone is formed against the E coli

bacteria Fig 3.5 A represents the normal silk suture,Fig 3.5 B represents the inhibition zone against destroying the E coli bacteria by the Moringa coated silk suture for at least 24 hours.

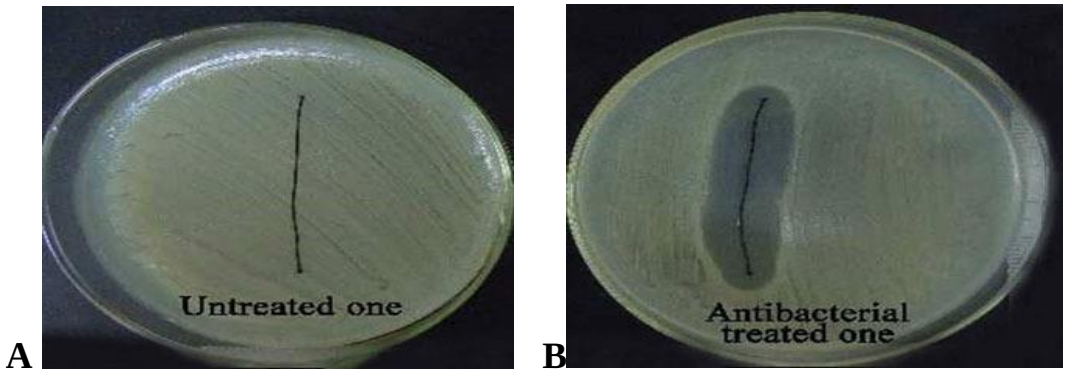


Fig 4.11 (A) represents the normal silk suture (B) represents the inhibition zone of Moringa coated silk suture

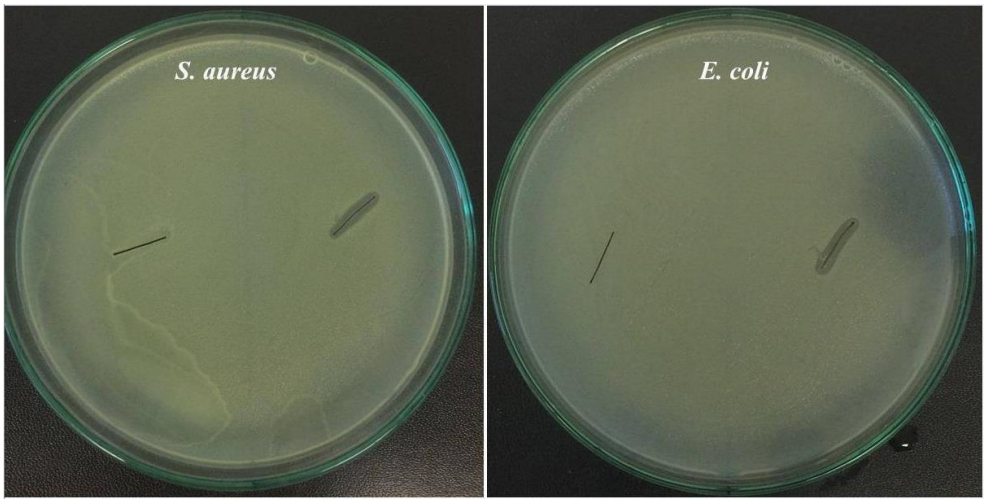
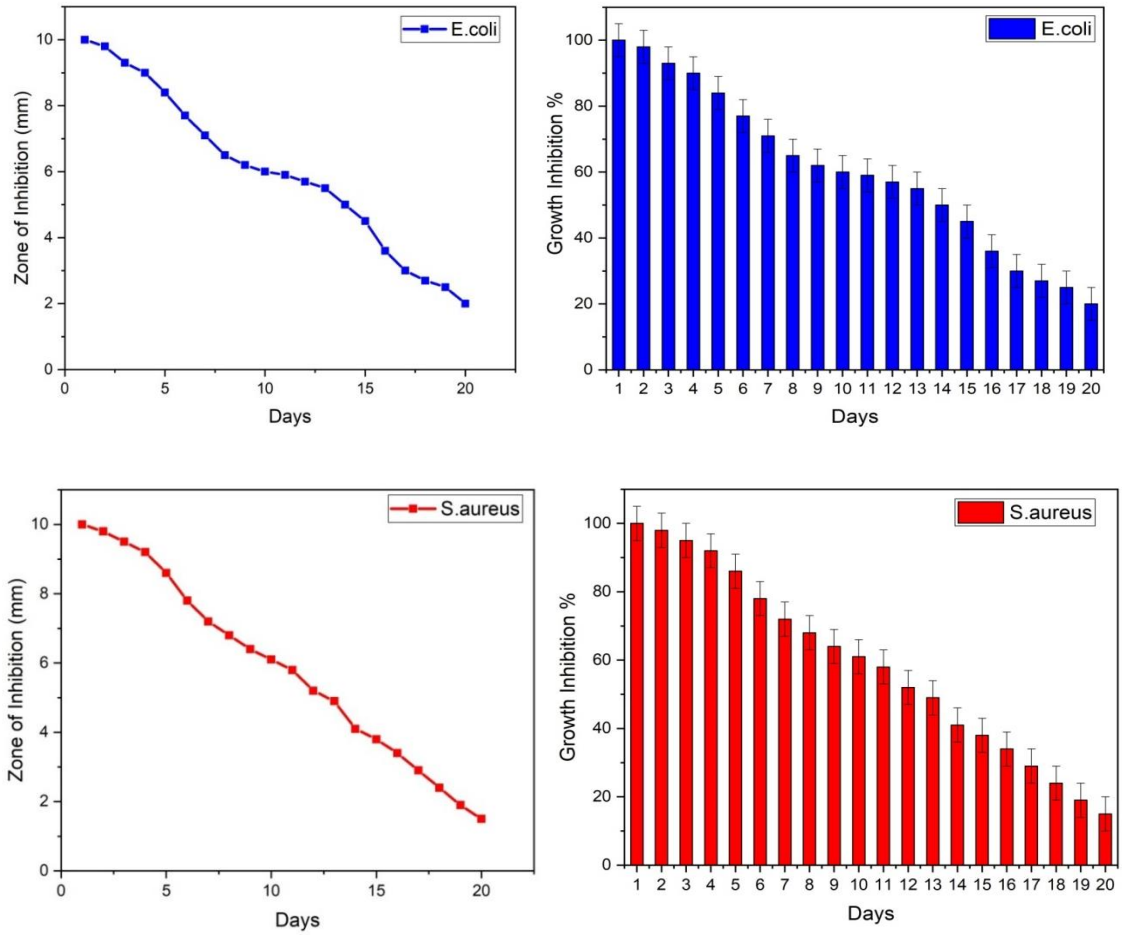


Fig 4.12 comparisons of normal silk suture and Moringa coated silk suture against the E coli strain, an inhibition zone of Moringa coated silk suture against the E coli strains

We use the ANOVA to study the day-by-day change in an inhibition zone against the E coli bacteria .no statistical difference occurs between the time points. By comparing the statistically significant difference is seen at day 7. Our Chatosin and Moringa coated silk suture is playing a vital role against the fresh host of E Coli bacteria every day. from the results of this study Fig 3.5.1 confirms that our Moringa coated silk braided suture can work against the E coli bacteria by making an inhibition zone which is shown. The

approximate time to render the growth of the E coli bacteria is 4 weeks by making an inhibition zone by Moringa coated silk braided nonabsorbable suture.

Gram Negative *Escherichia Coli*



S. aureus is one of the common microbes attacking the silk while being pathogenic to humans causing skin infections. It was proven earlier that Moringa have better inhibitory effect over gram positive bacteria due to structure of bacterial cell wall. In our study, we could observe that Moringa coating present on silk suture fiber effectively inhibited the growth of microbe up to 20 days and covering a wide area of 1 -0.1 cm. Normally, the sutures are removed after 14 days of surgery depending on the anatomic location.

4.6 Drug release of a Moringa and chitosan

We can see the drug release concerning the time in Fig (4.13). When we see the trend of the curve of drug release of the Moringa and chitosan. There is a noticeable small burst of increasing curve at the beginning of the drug release curve. Both Moringa and chitosan are released within the first day. The small little burst, in the beginning, shows that 14 and 16 % of total Moringa and chitosan are released totally. After the burst, there is a linear behavior in the drug release curve which shows the daily release of both Moringa and chitosan drugs.

Spectroscopically we can confirm the release of both Moringa and chitosan takes 5 weeks period. Moringa shows a very effective behavior inhibition against the E coli.

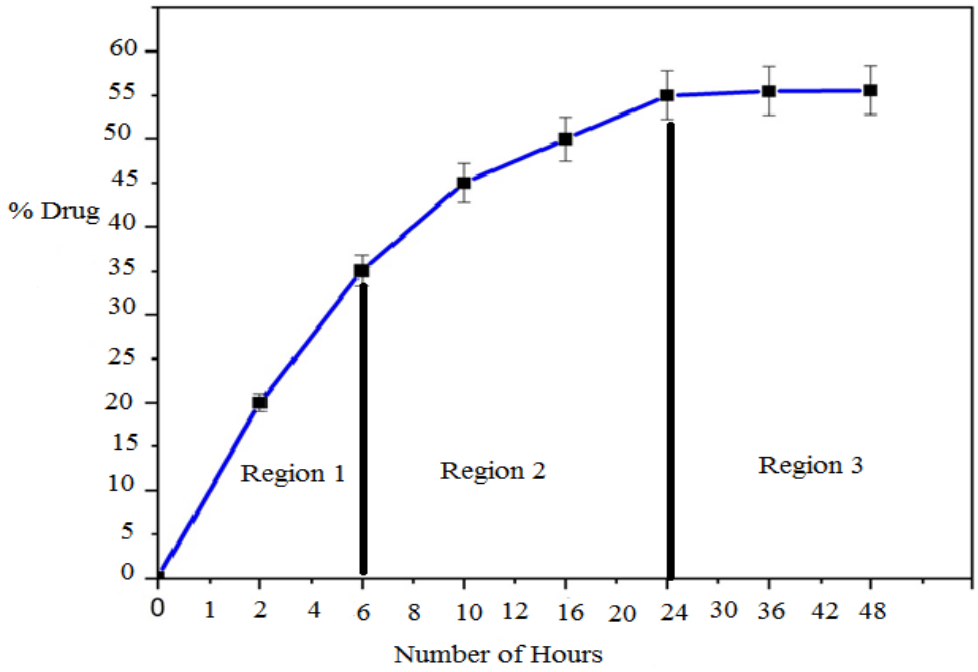


Figure 4.13 Drug release of Moringa coated silk sutures

Future directions

In our thesis work, we are working on the silk braided suture which is non-absorbable means not degrading by itself.we do a chitosan-based Moringa coating on the silk suture to optimize the results of coating and have unique surface texture properties. According to my opinion in a future direction, we can work on an improvement of the coating process and we can also work for many other non-absorbable sutures which are used for the surgery. The EPD coating process is working for the conductive substrate so we can find many others methods to make our substrate conductive for EPD coating.

5.1 How to improve the coating process

Improvement in the coating process of the EPD

When we coat our sample with Moringa by using EPD.We see a delaminating issue on the silk suture. Delamination issues mean failure in the material and material is broken into layers. However, delamination issues are not affecting the anti-microbial and anti-inflammatory activity of the silk suture. When we do a pull test after that mechanical test the cracks are clear.

The level of adherence of Moringa coating on the silk suture is due to the surface roughness of the silk braided suture. When we do a Moringa coated in the monofilaments suture the delaminationissue affectsit differently. Monofilaments have a very unique effect on the delaminationeffects. There are a few suggestions due to which we can counterwith the delamination effect

We can do a treatment to enhance the adherence of the moringa coating on the silk suture. The first thing no surface treatment is done on the surface of silk suture before the electrophoretic deposition. By doing a plasma (N2) treatment we can increase the reactivity of the silk suture which helps to form a firm moringa coating on the surface of silk braided nonabsorbable suture. I think we do not use cross-linker polymer. If we use crosslinker polymer it should create functional sites for binding of chitosan-based Moringa coating on the silk braided nonabsorbable suture.

5.2 Surface modification of the silk suture

We can do the surface modification of the silk suture by introducing the plasma (N2) treatment. We can do EDX or XPS to check the increase in Nitrogen on the silk suture. We can also add some cross-linking polymers to active the amides on the silk suture which helps to increase the reactivity of the silk suture.

Surface modifications affect on mechanical properties of the silk suture

When we do a surface modification on silk suture then we can check whether these modifications have toaffect the mechanical properties of silk suture or not for that purpose we again do a pull test. We can also do a T bend test which is used to measure the angle of bending at which failure or cracks start propagating on the surface of the silk suture. We can also do a lap shear test which tells us the strength of the bond of Moringa coating on the surface of the silk suture.

When the silk suture is dehydrated there will be a difference in the mechanical properties of the sutures. In our thesis work, we do most of the tests on a dry state of the suture. So when we do an EPD coating the suture is passed through an aqueous suspension so due to rehydration some of the cracks are generated on the surface of the coated suture. To check the mechanical properties on the surface of the coated suture, we should test the suture in different environments to measure the change in mechanics.

Alternative coating of the surgical sutures

There are two types of surgical sutures. One absorbable suture degrades by itself. Most surgeon uses absorbable silk sutures for internal surgery. We cannot do multiply times internal surgery to unstitch the sutures so the surgeon prefers absorbable sutures. We can also do a dual drug delivery system for absorbable silk sutures

We do a coating on the absorbable suture but a question is arises regarding the degradation profile.

Degradable Moringa coating on absorbable sutures

With the help of the EPD Electrophoretic deposition method, we can do a degradable Moringa coating on absorbable sutures. In General, there is a lot of potential in future applications of the sutures. Moringa coated with the EPD process have a wide range of applications. The EPD coating process which is mentioned in our study is very simple and this could have a variety of biomedical applications which have an infection or inflammations interests.

References

1). Tshabalala, T., Ndhlala, A.R., Ncube, B., Abdelgadir, H.A. and VanStaden, J., (2019). Potential substitution of the root with the leafin the use of *Moringa oleifera* for antimicrobial, antidiabetic, andantioxidant properties. *South African Journal of Botany, 129*(2020),pp.106–112.

2). Chin, C.-Y., Jalil, J., Ng, P.Y. and Ng, S.-F., (2018). Development and formulation of *Moringa oleifera* standardized leaf extract film dressing for wound healing application. *Journal of Ethnopharmacology,212*, pp.188–199.

3). Huang, J., Wang, Z., Krishna, S., Hu, Q., Xuan, M., and Xie, H., (2020). Environment-sensitive hydrogels as potential drug delivery systems for the treatment of periodontitis. *Materials Express*, *10*(7),pp.975–985.

4). Altiok, D., Altiok, E. and Tihminlioglu, F., (2010). Physical, antibacterial, and antioxidant properties of chitosan films incorporated with thyme oil for potential wound healing applications. *Journal of MaterialScience: Materials in Medicine, 21*(7), pp.2227–2236.

5). Besra L, Liu M (2007) A review on fundamentals and applications of electrophoretic deposition (EPD). Prog Mater Sci 52:1–61

6).P Sarkar, D De, T Uchikochi, L Besra (2012) Electrophoretic deposition (EPD): fundamentals and novel applications in the fabrication of advanced ceramic microstructures. In: Electrophoretic deposition of nanomaterials. Springer, New York, pp 181–215

7).E Harsanyi (1933) Method of coating radiant bodies. US Patent 1,897,902, 14 Feb (1933)

8). Sajid MS, McFall MR, Whitehouse PA, Sains PS. A systematic review ofabsorbable vsnon-absorbable sutures used for the closure of surgical incisions. World J Gastrointest Surg. Baishideng Publishing Group Inc; (2014) **Dec27**;6(12):241–7.

9). Gys T, Hubens A. A prospective comparative clinical study betweenmonofilament absorbable and non-absorbable sutures for abdominal wall closure. Acta Chir Belg. (1989)Sep;89(5):265–70.

10). Cummings SH, Grande DA, Hee CK, Kestler HK, Roden CM, Shah NV, et al. Effect of recombinant human platelet-derived growth factor-BB-coated sutures on Achilles tendon healing in a rat model: A histological and biomechanical study. J Tissue Eng. SAGE PublicationsSage UK: London, England; (2012);3(1):2041731412453577.

11). Fuchs TF, Surke C, Stange R, Quandt S, Wildemann B, Raschke MJ, et al. Local delivery of growth factors using coated suture material. ScientificWorldJournal. Hindawi;(2012;2012)(4755):109216–8.

12). Matalon S, Kozlovsky A, Kfir A, Levartovsky S, Mazor Y, Slutzky H. Theeffect of commonly used sutures on inflammation-inducing pathogens – An in vitro study. Journal of Cranio-Maxillofacial Surgery. (2013) Oct1;41(7):593–7.

13). Akhter MSJ, Verma R, Madhukar KP, Vaishampayan AR, Unadkat PC.Incidence of surgical site infection in postoperative patients at a tertiary care center in India. J Wound Care. MA Healthcare London; (2016)Apr;25(4):210–2–214–7.

14).Renko M, Paalanne N, Tapiainen T, Hinkkainen M, Pokka T, Kinnula S, etal. Triclosan-containing sutures versus ordinary sutures for reducing surgical site infections in children: a double-blind, randomized controlled trial. The Lancet Infectious Diseases. (2017) Jan1;17(1):50–7.

15). Defazio A, Datta M, Nezhat C. Does the use of Vicryl™ Plus AntibacterialSuture Decrease the Incidence of Umbilical Infection When Compared to Vicryl™ Suture? Fertility and Sterility. (2005)Sep;84:S161.

16). Haley RM, Rectum von HA. Localized and targeted delivery of NSAIDsfor treatment of inflammation: A review. ExpBiol Med (Maywood). (2018) Jan