

**MECHANICS OF BIOMATERIALS: SUTURES AFTER THE SURGERY<sup>1</sup>**

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**Abstract – This project discusses the development, standard and properties of mechanics of biomaterials employed in sutures realized after surgery. The treatment of many human disease conditions requires surgical intervention in order to assist, augment, sustain, or replace a diseased organ, and such procedures involve the use of materials foreign to the body, either before, during or after the surgery. Poor selection of materials can lead to clinical problems. The design or selection of a specific biomaterial depends on the various properties for the intended medical application. Physical properties that are generally considered include hardness, tensile strength, modulus, elongation; and fatigue strength. This project includes details of sutures and biomaterials for this particular application. The materials that are used in sutures: Polymers, stainless steel, silk and nylon.**

**Keywords-** Sutures, polymers, stainless steel, silk and nylon.

**INTRODUCTION**

Sutures are used in an attempt to improve and speed healing. Many different types of materials can be used to close a wound. These materials range from a special glue to wire staples, and from animal protein to synthetic thread-like materials. Sutures are used to close cuts from injuries or surgery and other procedures. Sutures are commonly used on the skin, but can also be used for internal tissues, organs, and blood vessels. One important distinction among different kinds of skin sutures is whether the sutures are absorbable or nonabsorbable (Table 1). Absorbable sutures dissolve on their own and may not require a return visit to the surgeon. Nonabsorbable sutures must be removed. The type of suture used is often related to the provider's preference as well as the type and location of a wound. This paper presents biomaterials for sutures.

**RESEARCH ADVANCES [1]**

Since the beginning of surgical history, wound closure is an important critical stage in surgery; surgical sutures play a prominent role. In the first half of this century, it was much less difficult for surgeons to select the proper suture, the only available sutures were natural products. Thus, the surgeon had a choice of silk, cotton or catgut.

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<sup>3</sup> The numbers in the parenthesis refer to references in the bibliography.

**Table 1.** Classifications of sutures [1].

<b>Absorption ability</b>	<b>Origin</b>	<b>Configuration</b>
Absorbable	Natural polymers (derived from animals), synthetic polymers	Monofilament, multifilament (braided or twisted), composite
Nonabsorbable	Natural polymers (derived from plants), synthetic polymers, metals	Monofilament, multifilament (braided or twisted), composite

As time passed, a variety of sutures have been used (to name only a few): nylons, polyesters and metals. The earliest use of gut can be traced back to the ancient Greek physician Galen. The eighteenth century brought the ability to chemically alter the properties of gut. By the twentieth century, cotton and treated natural materials had come to be the most widely used materials for suturing.

The invention of nylon and polyester propagated the popularity of cotton and treated natural materials, polyethylene, polypropylene, polyglycolic acid, polyglactin 910, and a large number of textile materials. So suture manufacturers are trying to provide the surgeon with sutures that are as close as possible to the ideal. Such sutures must be biological compatible and of adequate strength.

**SUTURE CHARACTERISTICS [10]**

The choice of a particular suture material should be based on the patient, the wound, the tissue characteristics and the anatomic location. A surgeon's selection may not be specifically based on scientific data, but rather, on the preferences that he or she learned from mentors and/or training. Understanding the various characteristics of available suture materials is important to make an educated selection.

No one suture possesses all desirable characteristics. The optimal suture is easy to handle and has high tensile strength and knot security. Any tissue reaction should be minimal, and the material should resist infection and have good elasticity and plasticity to accommodate wound swelling. A low cost is preferred. Although some of the newer materials available possess many of these properties, no one material is ideal, and compromises must be made.

Sutures possess characteristics that determine its utility. The physical characteristics of sutures include their configuration, diameter, capillarity and fluid absorption, tensile strength, knot strength, elasticity, plasticity, and

memory. The configuration is based on the number of strands of material used to fabricate the suture; a suture can be monofilament (ie, single-stranded) or multifilament (ie, multistranded).

### **1. Size**

United States Pharmacopeia (USP) sizes are standardized and related to a specific diameter range (in millimeters) that is necessary to produce a certain tensile strength. These diameter ranges vary with the different categories of suture material. These categories include natural collagen, synthetic absorbable, and synthetic nonabsorbable materials. Sizes are expressed with zeroes, that is, more zeroes indicate a smaller size. Capillarity is correlated with the tendency of the material to absorb and retain both fluid and bacteria. Multifilament sutures tend to have greater capillarity.

### **2. Tensile strength**

The tensile strength of a material is determined by the weight required to break a suture divided by its cross-sectional area. The rate of tensile strength loss is not the same as its absorption and varies among suture materials. The implantation and tying of sutures decrease their strength. Dry, unused absorbable sutures lose 4-13% of their initial strength after they are soaked in sodium chloride solution for 24 hours. Knotted sutures have two thirds the strength of unknotted sutures. In selecting sutures, it should be noted that the tensile strength of a suture need not to exceed that of the tissue it is securing.

### **3. Knots**

The knot is the weakest portion of the suture. Its strength is defined by the force necessary to cause slippage. The two types of knots used in dermatologic surgery are flat knots and sliding knots. Flat knots include square knots and surgeon's knots. Surgeon's knots differ from square knots in the initial throw. Two wraps around the needle driver define the surgeon's knot. Although these add no strength to the knot, they decrease the tendency of the wound to separate when the suture is tied.

Generally, flat knots are more secure than sliding knots; however, the strength of a nonidentical sliding knot with one extra throw is comparable. Three-throw flat knots are appropriate for use in dermatologic surgery; however, the suture material may affect the number of throws needed for security. Extra throws generally do not increase the strength of a properly tied knot; they only add to its bulk and therefore any potential tissue reaction.

### **4. Plasticity**

Plasticity is the ability of the suture to retain its new form and length after stretching. Plasticity allows a suture to accommodate swelling and therefore decreases the risk of strangulated tissue and crosshatch marks. However, as swelling subsides, the suture retains its new size and may not continue to adequately approximate the wound edges.

Elasticity is the ability of a suture to regain its original form

and length after stretching. After the swelling of a wound recedes, the suture returns to its original length and keeps the wound well approximated. Most sutures are elastic; few are plastic. Memory is the ability of a suture to return to its original shape after its deformation by tying. Memory is related to plasticity and elasticity. A suture with a high degree of memory, particularly a monofilament suture, is stiff and difficult to handle; the knots are less secure, and they may require an extra throw to prevent loosening of the knot.

### **5. Handling characteristics**

Handling characteristics of suture materials include their pliability and the coefficient of friction. Pliability refers to the ease with which a suture can be bent. The coefficient of friction is a measure of the slipperiness of the suture. Sutures with a high coefficient of friction (generally multifilaments) are more difficult to pass through tissue (because of tissue drag) and cause a greater degree of tissue injury. However, these sutures are easier to handle and better for knot tying. Also, the knot strength is proportional to the coefficient of friction; the ease and comfort of suture removal is related to this characteristic.

### **6. Tissue reaction**

Different suture materials are associated with various degrees of tissue reaction. Significant inflammation reduces the resistance to infection and delays the onset of wound healing. The type of material and the suture size are the major factors that determine the reactions. Natural materials are absorbed by proteolysis, which causes a significant inflammatory response. Synthetic materials are absorbed by hydrolysis, which minimizes such reactions.

Multifilamentous suture material is associated with greater reactivity because of its capillarity, and it may promote infection if bacterial contamination occurs during or shortly after surgery. Tissue reactivity to different suture materials (ie, silk, plain and chromic catgut, polyester, nylon, Vicryl, Maxon, Prolene) in rats seven days after surgery have been evaluated histologically. The study did not reveal any significant differences in tissue reactions; this finding suggests that the reaction caused by surgical trauma was a greater influence than the suture material.

Allergic reactions to suture materials are rare and are most specifically seen in association with chromic gut. Chromic acids may provoke a reaction in individuals who are chromate sensitive. The amount of suture placed in a wound, particularly with reference to the knot volume, affects the inflammatory reaction. The suture size contributes more to knot volume than the number of throws. The volume of square knots is less than that of sliding knots, and knots of monofilament sutures are smaller than those of multifilament sutures.

## SUTURE ACCESSORIES [10]

### 1. Needles [10]

Needles are necessary for the placement of suture material in a wound. Needles should be made of high-quality stainless steel, sharp enough to penetrate tissue with minimal trauma, rigid enough to resist bending, and malleable enough to bend before breaking. The sharpness of the needle is determined by the method of sharpening. Hand-honed or electrohoned needles are sharper than those processed by machine grinding. Sharper needles pass more easily through tissue and create less trauma to the wound. They are ideal for fine cosmetic work. The cost of needles is based on the quality of the stainless steel and their sharpness. In choosing a needle for cutaneous surgery, consider the tissue thickness and type, location, need for cosmesis, suture size, and cost.

#### a. Needle structure [10]

The structure of a needle includes 3 standard components: the shank or eye, the body, and the point. The shank is the portion of the needle that is attached to the suture. Swaged needles are preferred in dermatologic surgery. They have a hollow shank into which the manufacturer has secured the suture. This portion is both the thickest and weakest part of the needle.

The body is the portion of the needle from the end of the point to the contour change at the beginning of the swage. In cutaneous surgery, the body is usually curved, and its curvature based on a fraction of the arc of a circle; 3/8-circle and 1/2-circle curvatures are most often used. The choice of a particular needle length, width, and curvature depends on the size and depth of the wound and the thickness and type of tissue to be sutured. In deep, narrow, or confined spaces, 1/2-circle needles are easier to handle. The cross-sectional shape of the body is round, triangular, oval, rectangular, or trapezoidal. The body may be ribbed to improve the holder's grip on the needle.

The main functions of the body are to interact with the needle holder and to transmit a penetrating force to the point. The needle holder should hold the needle at approximately one third the distance from the swage to the point. Holding the needle over the swage may cause it to bend or break. The point is the portion of the needle from the tip to the end of the taper at the maximum diameter of the needle. Three types of needle points are available: round, conventional-cutting, and reverse-cutting. The round point is tapered and has no cutting edges; it passes through tissue by stretching it, and this needle is used for suturing soft, elastic tissues (e.g., fascia, muscle) but not skin.

#### b. Needle selection [10]

In dermatologic surgery, the most commonly used needles are conventional-cutting and reverse-cutting needles, which

pass through tissue by cutting a path rather than stretching the tissue. Both have triangular shapes and 3 cutting edges. Two of the cutting edges are on opposing sides of the needle. The conventional-cutting needle has its third cutting edge on the inner curvature of the needle, and it has a tendency to cut through tissue if upward pressure is exerted. The reverse-cutting needle has its third cutting edge on the outer curvature. This needle is less likely to tear through tissue during suturing and is more commonly used for cutaneous procedures.

The selection of needles is confusing because manufacturers use varying designations for similar needles. Ethicon needles include FS (for skin), PS (for plastic skin), P (for precision point), and PC (for precision cosmetic) types. Sherwood, Davis and Geck needles include CE (cutting, E = 3/8 circle), PRE (premium, E = 3/8 circle), PR (premium, 1/2 circle), SBE (slim blade, E = 3/8 circle).

The FS and CE types are large, reverse-cutting, and sharp needles, and they are least expensive. They are useful in buried and percutaneous closure of wounds on the scalp, trunk, and extremities in which cosmesis is not crucial. The PS needle is similar to the FS needle, but it is sharper and better for cosmetic procedures in areas where the skin is thicker and tougher. The P needle also is a reverse-cutting needle, but it is sharper therefore, it is an excellent choice for use in thin, delicate tissues when cosmesis is important.

The PRE designation includes needles comparable to both PS and P needles. The PC and SBE needles are conventional-cutting needles, but they have a long, narrow, and very sharp tip that is less likely to tear through tissue; therefore, they cause very little tissue trauma during suturing. PC and SBE needles also are ideal for fine, detailed work. The United States Surgical Corporation make needles comparable to those made by Ethicon and Sherwood, Davis and Geck.

### 2. Staples [10]

Staples are formed from high-quality stainless steel and are available in regular and wide sizes. Staples are composed of the following: a cross-member that lays on the surface of the skin perpendicular to the wound, legs that are vertically placed in the skin, and tips that secure the staple parallel to the cross-member. Staples are relatively easy to place and may shorten the closure time by 70-80%. The primary utility of staples is in the closure of wounds under high tension on the trunk, extremities, and scalp. They are also used to secure split-thickness skin grafts. They are not used in delicate tissues or wounds in finely contoured areas, over bony prominences, or in highly mobile areas.

Several studies have been conducted to compare the use of staples and nylon sutures on the trunk, head, and neck. These give comparable cosmetic results. Advantages of staples include a decreased risk of tissue strangulation and infection, improved wound eversion, and minimal tissue reactivity. Disadvantages include the need for a second

operator to evert and reapproximate skin edges during staple placement, the greater risk of crosshatch marking, and less precise wound approximation. The staples usually cost more than that of suture material.

In dermatologic surgery, the staplers used are disposable and loaded with 5-35 staples, depending on the manufacturer. They are lightweight and have handles that are easy to grip and control. The width and height of the staples vary with the manufacturer. Most regular staples are 4- to 6-mm wide and 3.5- to 4-mm high. Wide staples for thicker skin are 6.5- to 7.5-mm wide and 4- to 5-mm high. For staple placement, the stapler is gently held on the surface of the skin, perpendicular to the wound, and the handle is squeezed, plunging the staple into the skin to form an incomplete rectangle. The depth of penetration is based on the pressure exerted on the stapler against the skin. To disengage the staple, the handle is released. If the stapler has an ejector-spring release, it is lifted vertically off the skin. If not, the stapler must be moved anteriorly or posteriorly.

The placement of staples is critical to avoid complications such as tissue strangulation and crosshatch marking. Staples should be inserted at 45° or 60° angles. As a wound swells, a staple placed at an acute angle rotates into a vertical position, leaving a space between the cross-member and the skin surface to accommodate swelling. If placed at a 90° angle, the staple cannot move and is likely to strangulate the tissue during swelling.

Staplers that are used widely in dermatologic surgery include Appose (Sherwood, Davis and Geck), Proximate (Ethicon), and Precise (3M). Staples are removed painlessly by using a specialized set of extractors.

### 3. Tapes [10]

Tapes are strips of microporous nonocclusive material (eg, paper, plastic, rayon fabric) backed by a thin film of acrylic polymer adhesive. They are useful as an adjunct to or a substitute for other wound closure materials. Although they are used most often to reinforce a wound after the removal of sutures or staples, they can also be used alone for wounds that are small, nonexudative, and under minimal tension.

The advantages of tapes include ease of use; comfort to the patient; and avoidance of tissue strangulation, infection, and crosshatch marks. Follow-up visits for their removal are not necessary. Allergies to the adhesive are uncommon. Disadvantages include lack of wound eversion, precise wound-edge approximation, and adhesion. Tapes have little usefulness in hairy or highly mobile areas. Moisture, soap, and wound exudate decrease the duration that tapes may remain in place. To maximize adhesion, the use of a liquid adhesive is essential. Mastisol (Ferndale Laboratories) and tincture of benzoin are available for this purpose; Mastisol has superior adhesive strength. After the wound is grossly reapproximated, the area should be degreased with alcohol,

acetone, or adhesive remover, and the liquid adhesive should be applied over the wound edges and the entire area to which the tapes will adhere. Once the adhesive has dried to a tacky feel, strips of tapes should be placed perpendicularly across the wound without overlapping each other. Additional tapes should not be used parallel to the wound to reinforce the tape edges because this application decreases adherence. Tapes that are kept dry and clean may remain adherent for 1-2 weeks.

Tapes are available in different widths (eg, 1/8 inch, 1/4 inch, 1/2 inch) and colors (eg, white, clear, flesh toned). Commonly available products include Steri-Strip Skin Closures (3M), Cover-Strip II (Beiersdorf), Proxi-Strip Skin Closures (Ethicon), and DermaSeal Skin Closure Strips (Personna).

### 4. Tissue Adhesives [10]

Cyanoacrylates for use in surgery have been available in Canada and Europe for 20 years, but products suitable for use in dermatologic surgery have not become available until recently. Octylcyanoacrylate (Dermabond) polymerizes in an exothermic reaction on contact with fluid to form a 3-dimensional, strong, flexible bond with uses comparable to those of 5-0 monofilament nylon. Octylcyanoacrylate is available in 0.5-mL capsules for individual use.

Dermabond is useful for the closure of simple lacerations in children and uncooperative patients. It is also useful for the closure of incisions under casts or in cases in which follow-up is difficult. Dermabond is not used in areas that are highly mobile or subject to friction (eg, over joints, hands, feet). Dermabond is quick and easy to apply; only one tenth to one fourth the time required for suture placement is needed. It provides an antimicrobial and waterproof coating, but repeated washing removes the adhesive in a few days. The cosmetic outcome generally is good, and no postoperative visit is required for its removal.

The cost per unit of Dermabond is higher than that of comparable sutures; however, Osmond et al performed a cost analysis, comparing the use of sutures to tissue adhesives in an emergency room. They accounted for all equipment, healthcare worker time, and loss of income for follow-up visits and found that the use of the tissue adhesive was cost effective overall.

The use of Dermabond requires that the wound be completely reapproximated before its application. In dermatologic surgery, most wounds need buried sutures prior to the application of the adhesive. If the adhesive seeps into the wound bed, healing is impaired.

Before the application of Dermabond, the skin must be defatted with alcohol or acetone. Dermabond is applied in a thin layer over the entire wound and extending 5-10 mm beyond the wound edge. The formation of the bond produces heat that the patient can feel. Once the layer is

dried (10-30 seconds), a second layer is applied. Three to 4 layers are necessary. No additional bandaging is required, and the patient is advised not to perform wound care at home. In 7-14 days, most of the adhesive sloughs off with the epidermis, and the remainder may be removed with soap and water or petroleum jelly.

In addition to its indication for use as a surgical adhesive, Dermabond is approved by the Food and Drug Administration (FDA) for use as a barrier against common bacterial microbes, including certain staphylococci, pseudomonads, and *Escherichia coli*.

### **PAST PRESENT AND FUTURE SCOPE [8]**

The history of wound closure dates back to 5500-3000 BC, the origin of surgery. Early wound closure devices were made of natural materials such as flax, silk, linen strips and cotton. These natural materials were lubricated in oil and wine prior to application so as to reduce tissue drag and create a cleaner wound closure procedure. Another early form of wound closure technique involved the use of mandibles of soldier ants. With the development of synthetic polymers and fibers, synthetic sutures were introduced into the market. These sutures allow designers to engineer the polymer configuration, the fiber type and size and the surface lubricant and coating for specific applications. Today, surgical sutures come in many forms: Natural, synthetic, absorbable and non absorbable. The application depends on the surgeon's preference as well as the specific site and clinical technique being performed.

Today's suturing techniques are responsible for two main adverse effects. Sutures require knots so as to ensure optimal tissue closure strength. The goal of wound closure is to bring the edges of the wound together not only with sufficient strength to prevent dehiscence, but also with a minimal residual tension and compression of the tissue. First, the knot tying process leads to residual forces and distortion of the tissue that can cause impaired blood perfusion through the capillaries and can compromise the healing process. The body's natural reaction to foreign materials causes the second adverse effect. Once implanted, sutures provoke a significant inflammatory response, particularly at the knot site, because the knot represents the major mass of foreign material that is concentrated in a small volume. This has led to a continuing debate among surgeons as to how many throws should be incorporated into a surgical knot so as to maximize strength and minimize the tissue reaction.

In 1967, A.R. Mackenzie published an article about an experimental multiple barbed suture. He stated that during insertion the barbed suture minimized tissue damage, which led to milder foreign-body reaction. His study showed that barbed sutures could be used successfully in flexor tendon repair. However, the nylon barbed sutures had to be

removed after a four week period, which led to additional late surgical trauma.

Future experimentation, design and engineering will lead to better understanding of the barbed suture. The initial product has given positive data when compared to current sutures that require knots. Experiments are currently being performed that test the tissue holding capacity of the sutured wound under stress. The use of microelectronic mechanical systems is being considered to better understand the reaction between tissue and the individual barbs. Future design applications will look at how different barb geometries affect the performance of the suture and its ability to hold different types of tissue. Also micro-machining technologies are being evaluated to ensure the optimum control over different manufacturing processes. Because the bidirectional barbed suture reduces problems that are associated with current sutures in the market, it is believed that this novel product will have a significant impact on the future wound closure industry. New textile products will continue to expand the traditional thinking about sutures and wound closure devices.

#### **a. Biodegradable Polymers [9]**

1. Potential advantages: Hardware removal not necessary, reducing morbidity and cost. Stiffness of polymer decreases as stiffness of fracture callus increases. Can possibly be used in future for controlled release of antibiotics or stimulants to healing.
2. Requirements: Adequate mechanical strength for the application sufficient strength over a sufficient period of time to maintain enough stability for the fracture to heal and prevent loss of reduction. Degradability into products that are not harmful.
3. Examples: Polyglycolic acid, Polylactic acid, Copolymers.
4. Only about 1/20<sup>th</sup> the stiffness and strength of stainless steel.
5. Used in ankle fractures with poor results.
6. Used in phalangeal fractures with better results.

#### **b. Stainless Steel [9]**

1. Iron based alloy containing chromium, nickel, molybdenum. Usually annealed, cold worked or cold forged for increased strength. A range of strength and ductilities can be produced.
2. Strong and cheap.
3. Cheap.
4. Relatively ductile therefore easy to alter shape. Useful in contouring of plates and wires during operative procedures.
5. Relatively biocompatible.
6. The chromium forms an oxide layer when dipped in nitric acid to reduce corrosion and the molybdenum increases this protection when compared to other steels.

7. Can still undergo corrosion if carbon gets to the surface.
8. High Young's modulus of 200 GPa (10× that of bone) so can lead to stress shielding of surrounding bone which can cause bone resorption.
9. Used in plates, screws, external fixators, I.M. nails.
10. Composition of 316L Stainless Steel: Iron- 60%, Chromium- 20% (major corrosion protection), Nickel- 14% (corrosion resistance), Molybdenum- 3% (protects against pitting corrosion), Carbon- 0.03% (incr. strength), Manganese, Silicon,P,S,- 3% (control manufacturing problems).

### c. Nylon sutures [10]

Introduced in 1940, nylon was the first synthetic suture available, and it is most commonly used nonabsorbable material in dermatologic surgery. It is available in both monofilamentous and multifilamentous forms. Nylon has a high tensile strength and, although it is classified as nonabsorbable, it loses tensile strength annually when it is buried in tissue. Multifilamentous forms retain no tensile strength after being in tissue for 6 months, whereas monofilamentous forms retain as much as two thirds of their original strength after 11 years. Monofilament nylon is stiff. Therefore, handling and tying are difficult, and knot security is low. The suture also may cut easily through the thin tissue.

Multifilamentous forms have better handling properties but greater tissue reactivity and cost. They are used infrequently in dermatologic surgery. Monofilament nylon is relatively inexpensive and available in multiple colors (eg, black, green) or as a clear material. Although its greatest use is as a percutaneous suture, yet clear nylon, because of its low tissue reactivity, can be used as a buried suture in situations in which prolonged dermal support is necessary.

### d. Silk sutures [10]

Silk was first widely used as a suture material in the 1890s. It is a braided material formed from the protein fibers produced by silkworm larvae. Although silk is considered a nonabsorbable material, it is eventually degraded in tissue within 2 years. Silk has excellent handling and knot-tying properties and is the standard to which all other suture materials are compared. Its knot security is high. Its tensile strength is low, and its tissue reactivity is high. Suture removal can be difficult and painful because the braided material becomes infiltrated with cells and encrusted with debris while silk sutures are implanted in the skin.

Silk is a soft, pliable suture material that is comfortable for patients and unlikely to tear through even delicate tissues. As a result, it is a good choice for use in mucosal tissues or intertriginous areas. Silk also is useful as a temporary

suture to elevate or retract tissues for improved visibility during surgery. It is available in black.

## ABSORBABLE SUTURES [1]

Sutures are classified as absorbable or nonabsorbable. Sutures can be further classified as natural or synthetic and multifilament or monofilament. Numerous manufacturers of sutures exist; however, Ethicon, Sherwood, Davis and Geck, Look, and United States Surgical Corporation manufacture most of the sutures that are used in dermatologic surgery. Most sutures are available in standard 18- and 27-inch lengths. Several manufacturers provide sutures in 9- and 10-inch lengths. These shorter sutures are for biopsy or small wound closures, and they also are less expensive.

Absorbable suture is one that loses most of its tensile strength within 60 days after placement. Most absorbable material is used as a buried suture to close the dermis and subcutaneous tissue and to reduce wound tension. The natural absorbable suture available is surgical gut, or catgut. Synthetic multifilamentous materials include polyglycolic acid (Dexon; Sherwood, Davis and Geck) and polyglactin 910 (Vicryl; Ethicon). Monofilamentous forms include polydioxanone (PDS; Ethicon), polytrimethylene carbonate (Maxon; Sherwood, Davis and Geck), and polyglecaprone (Monocryl; Ethicon).

Absorbable sutures (Table 2) are temporary due to their ability to be absorbed or decomposed by the natural reaction of the body to foreign substances. It is one that placement. Most absorbable material is used as a buried suture to close the dermis and subcutaneous tissue and to reduce wound tension. The natural absorbable suture available is surgical gut, or catgut. Synthetic multifilamentous materials include polyglycolic acid (Dexon; Sherwood, Davis and Geck) and polyglactin 910 (Vicryl; Ethicon). Monofilamentous forms include polydioxanone (PDS; Ethicon), polytrimethylene carbonate (Maxon; Sherwood, Davis and Geck), and polyglecaprone (Monocryl; Ethicon). Characteristics are shown in tables 2 and 3.

Surgical gut or catgut was the first absorbable suture material available. It is a twisted fiber formed from the collagen of the intestines of sheep or cows. Surgical gut is packaged in alcohol to prevent it from drying and breaking.

Three forms are available: plain, chromic, and fast absorbing (Ethicon). Plain gut elicits a marked inflammatory reaction in tissue and maintains its tensile strength for only 7-10 days after implantation. Catgut maintains its tensile stringy for as long as 21 days. Generally, it is completely absorbed by 70 days; however, the loss of strength and absorption varies greatly. Chromic gut is plain gut treated with chromium salts to slow its absorption and decrease tissue reactivity. Its tensile strength is maintained for as long as 10-21 days, and complete absorption does not occur until at least day 90.

Plain and chromic gut has limited uses in dermatologic surgery. This material is used in the closure of mucosal surfaces or as ligatures for blood vessels, among other uses. Fast absorbing gut is plain gut that is treated with heat which results in speedy absorption. It was designed for percutaneous suturing, and the material maintains its tensile strength for only 5-78 days. It is completely absorbed within 2-4 weeks. Fast-absorbing gut is useful for the percutaneous closure of facial wounds under low tension and for securing both split –and full-thickness skin grafts.

Polyglycolic acid (Dexon S; Sherwood, Davis and Geck) was introduced in 1970 as the first synthetic absorbable suture. It has high tensile strength with a retention of 60% at day 7, 35% at day 14, and only 5% at day 28. Polyglycolic acid is completely hydrolyzed in 90-120 days. This multifilamentous suture is braided; therefore, it has good handling and knot security properties. However, its high coefficient of friction causes significant tissue drag. To minimize this drag, a coated form is available (Dexon II; Sherwood, Davis and Geck); this form slides easily through tissue and is easier to tie. The tissue reactivity associated with this material is relatively low, but the multifilament nature may potentiate infection. Polyglycolic acid is available as a clear or green suture.

Another Ethicon product, Vicryl Rapide, is polyglactin 910 that is ionized with gamma rays to speed its absorption. It is completely absorbed in 35 days. Although used primarily

as a buried suture, polyglactin has been used for percutaneous closures without adverse outcomes and with resultant cost savings.

## 1. Biomaterials for Absorbable Sutures

### a. Polyglactin [10]

Introduced in 1974, polyglactin was the second synthetic absorbable suture material available. Like polyglycolic acid, polyglactin is braided and has similar handling and knot security properties. Polyglactin 910 (Vicryl; Ethicon) is coated with polyglactin 370, which facilitates knot tying and reduces tissue drag; however, this coating also reduces knot security and requires the use of extra throws.

Its initial tensile strength is slightly greater than that of polyglycolic acid, and it is absorbed more quickly. Polyglactin retains 60% of its tensile strength at day 14 after implantation and only 8% of its original strength at day 28. It is completely hydrolyzed by 60-90 days. The tissue reactivity with polyglactin is low and slightly less than that of polyglycolic acid. Both suture materials may be transepidermally eliminated if they are buried too superficially in the dermis. Polyglactin is available as a clear or violet suture.

### b. Polydioxanone [4,10]

**Table 2.** Characteristics of Absorbable Sutures [10].

Property	Gut	Polyglycolic Acid	Polyglactin	Polydioxanone	Polytrimethylene Carbonate	Polyglecaprone
Handling	Fair	Fair-good	Good	Poor	Good	Excellent
Knot security	Poor	Fair-good	Fair	Poor	Good	Good
Tensile strength	Low	High	High	Moderate	High	High
	Proteolysis at 60-90 days, unpredictable	Hydrolysis at 90-120 days	Hydrolysis at 60-90 days	Hydrolysis at 180-210 days	Hydrolysis at 180-210 days	Hydrolysis at 90-120 days
Coefficient of friction	-----	High	Medium	Low	Low	Low
Memory	Low	Low	Low	High	Low	Low
Tissue reactivity	High	Low-moderate	Low-moderate	Low	Low	Low
Uses	Sutures in mucosal tissues, vessel ligation	Buried sutures	Buried sutures	Buried sutures in wounds requiring longer dermal support	Buried sutures in wounds requiring longer dermal support	Buried sutures
Other	-----	Low elasticity	Low elasticity	-----	-----	High elasticity
	-----	Clear or green	Clear or violet	Clear or violet	Clear or green	Clear

A synthetic monofilament absorbable suture (polydioxanone) was first available in 1982. Although its initial tensile strength is lower than that of the synthetic multifilament sutures; it retains its strength longer. At day 14 after implantation, it has 74% residual strength; at day 28, 58%; and at week 6, 41%. Complete hydrolysis occurs by 180-210 days. Polydioxanone is stiff and has poor handling and knot-tying properties. Knot security is like wise low and requires an additional throw.

A newer product that has replaced the original product is PDS-II (Ethicon), which has improved handling capabilities. As a monofilament suture, polydioxanone causes a minimal tissue reaction. It is useful in contaminated wounds or wounds in locations at greater risk for infection.

Polydioxanone also is useful as a buried suture in wounds requiring prolonged dermal support. Dermal support of a wound for 3 weeks to 6 months may reduce the spreading of scars. A 16% reduction in the spreading of scars could be accomplished by using dermal support for 3 weeks; and a 38% reduction in spread with the use of dermal support for 6 months. Polydioxanone is available as a clear or violet suture. Polydioxanone is more expensive than polyglycolic acid or polyglactin.

#### **c. Polytrimethylene carbonate [10]**

Polytrimethylene carbonate or polyglyconate (Maxon; Sherwood, Davis and Geck) was introduced in 1985 as another synthetic monofilament absorbable suture. It has a high initial tensile strength (greater than that of polydioxanone), and it retains monofilament absorbable suture.

It has a high initial tensile strength (greater than that of polydioxanone), and it retains 81% of its strength at day 14, 59% at day 28, and 30% at week 6. It is completely hydrolyzed by 180-210 days. Polytrimethylene carbonate is easier to handle and has greater knot security than polydioxanone, polyglactin, or polyglycolic acid. Its tissue reactivity is comparable to that of polydioxanone, and its cost is lower. Polytrimethylene carbonate is available as a clear or green suture.

#### **d. Polyglecaprone [10]**

The newest synthetic absorbable material is polyglecaprone (Monocryl; Ethicon). It was introduced in 1993. Polyglecaprone is very pliable despite its monofilament nature and, as a result, its handling and knot strength are excellent. Among all absorbable monofilament sutures, polyglecaprone has the highest tensile strength; however, only 20-30% of its strength is retained at day 14 after implantation. Complete hydrolysis occurs by 90-120 days. Polyglecaprone is most useful as a buried suture in wounds in which prolonged dermal support is not essential. Like other monofilament sutures, polyglecaprone has minimal tissue drag and tissue reactivity. It is available as a clear

material. The cost of polyglecaprone is comparable to that of polydioxanone.

#### **e. Natural Collagen [30]**

It comes from the submucosa of sheep intestine or the serosa of beef intestine. The medical use of collagen began decades ago when animal collagen was used in surgical sutures. Continued research led to the wide use of collagen in a number of applications, including heart valves and as an agent to help stop bleeding during surgery. A group of biochemists and physicians at Stanford University pioneered the concept of purifying animal collagen so it could be used to replace lost skin tissue.

#### **f. Plain gut [3]**

Sutures are absorbable sterile surgical sutures composed of purified connective tissue (mostly collagen) derived from the serosal layer of beef (bovine) intestines. These sutures are indicated for use in general soft tissue approximation and or ligation, including use in ophthalmic surgery, but not in cardiovascular or neurological surgery. The use of these sutures is contraindicated in patients with known sensitivities or allergies to collagen or chromium, as gut is a collagen based material. Chromic gut is treated with chromic salt solutions. Some advantages are: very high knot-pull tensile strength, good knot security due to special surface finish, improved smoothness due to the dry presentation of the thread, and excellent handling features. It is used in: strabismus, conjunctival, skin, urological, dental, gastrointestinal, subcuticular, obstetrical and gynecological.

#### **g. Polyglycolic acid [27, 28]**

It was first synthetic absorbable suture and has been used in millions of patients worldwide. Braided synthetic absorbable multifilament are made of polyglycolic acid and coated with N-Laurin and L-Lysine, which render the thread extremely smooth, soft and knot safe.

It has high initial tensile strength, guaranteed holding power through the critical wound healing period, smooth passage through tissue, easy handling, excellent knotting ability, secure knot tying, and unique bending and breaking resistance of the D-tek needles. It is used in Glaucoma, conjunctival, cataract, strabismus, plastic, skin, subcuticular, urological, pediatric, gastrointestinal, orthopaedic, dental, oral and gynecological.

#### **h. Polyglactine 910 [29]**

It is a braided co-polymer of glycolic and lactic acid that is surface treated with polyglactin 370 and calcium stearate and has received gamma radiation. This radiation alters the suture material's molecular structure and enhances its

absorption rate in vivo. Several reports on its use in pediatric, gynecological and general surgery.

Its advantages are: high initial tensile strength, guaranteed holding power through the critical wound healing period, smooth passage through tissue, easy handling, excellent knotting ability, secure knot tying, unique bending and breaking resistance of the D-tek needles. sutures used are now made of synthetic fibers, like polyglycolic acid.

## 2. Design Requirements [1]

Properties of sutures are divided in three groups. These determine the general performance or the suture during wound closure procedures and after implantation

- a. Physical characteristics (Preliminary information concerning suture material without dealing future interactions-mechanical or biological).
- b. Handling characteristics (mechanical behavior or the suture before, during and after wound closure).
- c. Biological properties (general biological responses of the patient after implantation and during wound healing).

Physical tests for sutures are either standard methods to demonstrate agreement or compliance with compendium requirements or research tests measuring fundamental properties simulating performance under operating conditions.

Some of the most common methods by which tests are conducted are also methods widely used in other areas of medicine or industry. A few examples of these methods or instruments are as follows: infrared spectrophotometers, projection microscopes, tensile testers, light microscopy and degradation studies in vivo.

“The United States Pharmacopoeia (USP XXII)” is the official compendium for the suture industry. It sets standards and guidelines for suture manufacturing. Only length, size (diameter), knot pull strength, and needle attachment force are defined and required by the USP.

Sutures are tested immediately after removal from their sterile packages without drying or conditioning, except when testing for compliance with British Pharmacopoeia (BP) or European Pharmacopoeia (EP) requirements which specify prior conditioning described in monographs for various suture types.

Size (diameter) is measured in “mm” on a special device (gauge of the dead-weight type with a presser-foot) under constant weight, between 0.02-1.3. The diameter of each strand is measured at three points corresponding roughly to one fourth, one-half and three-fourths of the strand length.

Knot-pull strength is measured in “kg” on a tensile strength tester. For measuring: the suture is tied with a surgeons knot with one turn around a flexible rubber tubing of 6.5 mm inside diameter and 1,6 mm wall thickness. The suture is then attached to a suitable testing machine and tested at a rate such that the specimen breaks in less than twenty seconds.

Some of the handling characteristics can be measured, like coefficient of friction and stiffness, which the stiffness of monofilament sutures is always higher than that of multifilament sutures of the same size and material; but some can only be evaluated subjectively by the surgeon’s

**Table 3.** Types of absorbable surgical sutures [1].

Generic Name	Trade Name	Manufacturer	Raw Material
<i>Natural Collagens</i>			
Plain gut		Ethicon, Davis & Geck	Submucosa sheep intestine
Chromic gut		Ethicon, Davis & Geck	Serosa of beef +Buffered chromicizing
Collagen (plain)		Davis & Geck	Beef flexor tendon
Collagen (chromic)		Davis & Geck	Beef flexor tendon + Buffered chromicizing
<i>Synthetics</i>			
Polyglycolic acid	Dexon S	Davis & Geck	Homopolymer of glycolic acid
Polyglycolic acid	Dexon Plus	Davis & Geck	Homopolymer of glycolic acid coated with poloxamer 188
Polyglycolic acid	Dexon II	Davis & Geck Ethicon	Homopolymer of glycolic acid coated with polycaprolate
Polyglactine 910	Vicryl (coated Vicryl)		Copolymer lactide-glycolic acid coated with calcium stearate and polyglactine 370
Polydioxanone	PDS	Ethicon	Polymer of paradioxanone
Polydioxanone	PDS-2	Ethicon	Modified PDS
Polyglyconate	Maxon	Davis & Geck	Copolymer of trimethylene carbonate and polyglycolic acid
Polyglecaprone 25	Monocryl	Ethicon	Copolymer ε-caprolactone and glycolide

or the patient's experience. Also flexibility, pliability, and smoothness are the subjective terms, dependent on the surgeon's opinion.

Suture material is a foreign body to the human organism and causes reaction in the tissue. Because any tissue injury incites an inflammatory response, we expect some degree of inflammation around each suture site. Both chemical nature of suture material and the physical configuration affect the possibility of infection and inflammation. Inflammation is always present for five days after suture placement, regardless of the suture material used. It is the subsequent chronic inflammatory reaction that separates the suture material from another.

For example synthetic sutures have a lower inflammation tendency than natural materials. Biological reaction to natural sutures is much higher than with synthetic sutures. Surgical catgut sutures, due to their natural origin excite the highest degree of tissue reaction. Thus, use of natural absorbable sutures in skin surgery is not recommended because of a bacterial infection that might occur due to inflammatory tissue response. In order to solve this problem, researchers coated the catgut strands with a thin layer of a biocompatible, biodegradable polyurethane. This provides protection from the inflammatory reaction, which occurs in the first days after the operation.

Also multifilament sutures are generally more problematic than monofilaments, due to the interstices in multifilament sutures, which are potential sites for transmission of bacterial infection.

Knots of suture also offer a heaven for bacteria; therefore the number of throws should be minimized on buried sutures.

Another biological response is tissue ingrowths, which is the tissue interaction with the filaments of the braided suture. The adhesion between the tissue and the suture surface causes a problem on the removal of the suture. And this can occur even with the monofilament sutures.

Also the length of the cut ends affects the adhesion. Thus it was suggested that the ends be cut off as closely as possible to the knot (but short as the safety of the knot permits) for preventing adhesion.

Other biological responses are allergy to the suture materials like allergies to catgut, nylon, and chromic salts added to catgut sutures have been reported.

The degree of tissue reactions to the suture materials like absorbable sutures depends not only on the physical and chemical properties but also on the suture mass that remains inside the tissue. The longer a suture mass stays in the human body, the more it causes tissue reactions.

In the last few years an experimental surgical suture has been developed that uses a low, direct current of electricity to kill germs causes less inflammation in tissues than do commonly used synthetic sutures.

Researchers reported that tissue exhibits milder inflammatory reaction to the new antimicrobial suture than to a common synthetic suture for up to 60 days.

Researchers are also working on synthetic fibers that will function both as sutures and as devices for local delivery of antimicrobials, such as povidone-iodine and tetracycline. The delivery of antimicrobial agents near the wound closure coupled with their slow release ability results in remarkable improvement in the healing process, with the danger of infection or inflammation greatly decreased. This is enabled with different types of applications like creating pores on the sutures. By coating the sutures with solutions or dispersions, pores filled with antimicrobial drugs, i.e., antibiotics or antiseptics. The coating did not influence the physical properties of the suture. Here the drug release properties can be controlled by varying the size of the pores produced on the surface of the suture.

### 3. Tensile Strength of Absorbable Sutures [1]

Tensile strength, dynamic properties, knotting characteristics are important factors for evaluation of different types of sutures. But when faced with a new suture material, the mechanical properties are of major concern to surgeons.

For example tensile behavior of Ethilon, Maxon and Novafil are similar to each other while Prolene and GORE-TEX exhibit different tensile behavior from each other and from the other materials. Also the ratios of the straight to knotted tensile strength differ for the biomaterials. But all suture materials have values considerably greater than the USP minimum requirement for knot-pull strength. The ratio of knotted to straight tensile strength is between 59 and 91% for all materials. Findings suggest that although knotting reduced the suture tensile strength, the decrease is not sufficient to affect the clinical use. Maxon showed a steep elastic region (high modulus) and high values of elongation such that the material exhibited the highest values of failure energy for all materials tested (Figure 1).

Suture should retain their tensile strength for supporting the healing tissue until the two-week period is over (Figure 1). Because of its chemical properties chromic catgut fails because of absorption. It retains only 15-20% of its original tensile strength by the second postoperative week, and usually lost most of its tensile strength by postoperative day 10. By contrast; during the critical two-week period Maxon and Vicryl are significantly stronger than PDS and chromic catgut. PDS and Maxon retained its tensile strength during the late postoperative period. Vicryl also lost most of its tensile strength by the 28th postoperative day (Table 4).

**Table 4.** Comparison of Monocryl with other absorbable sutures [4].

Material	Diameter mils	Straight-pull		Young's Modulus ksi
		Pull lb	Strength ksi	
Monocryl	15.03	16	91	113
PDS II	13.93	11	71	380
Chromic gut	15.7	9	47	358
Vicryl	13.74	15	103	211

If we compare the tensile strength of absorbable sutures studied in vivo from weeks 1 to 6; we can see that braided absorbable sutures, Dexon Plus and Vicryl, had lost one half of their tensile strength by 2 weeks and had no tensile strength by 4 weeks. But monofilament absorbable sutures Maxon and PDS showed longer half-lives (Maxon\_3 weeks and PDS\_6 weeks).

Also as seen in the figure 1, by 6 weeks, Maxon had virtually no tensile strength whereas PDS retained about

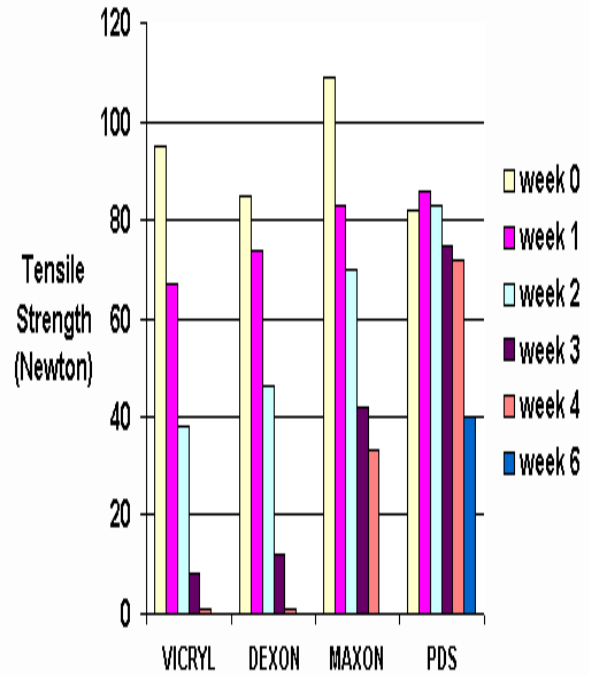
50% of its tensile strength. Researchers reported that; tensile strength loss and mass absorption indicate that the time for complete mass absorption is longer than the time for complete tensile strength loss.

Table 5 compares the time required for complete tensile strength loss and mass absorption of four synthetic absorbable sutures in vivo.

Tensile strength of Dexon and Vicryl were not able to be measured after 28 days postimplantation; while most of their mass were still present in the tissue for as long as 140 days. We can see that PDS and Maxon sutures retained their tensile strength longer and degrade less rapidly.

Braided sutures produced from polyglactine-910 (Vicryl) cause trauma and tissue drag. Thus, they are coated with vycril to minimize tissue drag. Also absorbable monofilament sutures like PDS II and Maxon do not handle as well as braids.

The new synthetic absorbable monofilament suture derived from segmented copolymer of e-caprolactone and glycolide, monocryl suture possesses the highest tensile strength. This polymer provides both good handling characteristic and high strength because of its complex polymeric system. Also the straight-pull strength is higher than the other types of sutures and it shows best handling properties of all the available monofilament absorbable sutures. But the % of elongation is not good like PDS II. They display minimal resistance during passage through tissue. They provide an in vivo breaking strength retention of approximately 20-30 % after two weeks, considered by many to be the critical wound healing period. Absorption on these sutures is between the 91st and 119<sup>th</sup> days of implantation, with slight or minimal tissue reaction. If we



**Figure 1.** Tensile strength of Vicryl, Dexon Plus, Maxon, and PDS sutures in vivo after 1 to 6 weeks [1].

**Table 5.** Comparison of four synthetic absorbable sutures [1].

Trade Name	Days of Total Strength Loss	Days of Total Mass Loss	Absorption Delay (days)
Dexon	28	50-140	22-112
Vicryl	28	90	62
PDS	63	180-240	117-170
Maxon	56	210	155

make the comparison of absorbable (Vicryl, Dexon Plus, Maxon, PDS) and nonabsorbable (Prolene, Silk, Ethibond, Ti-Cron) sutures; in tensile strength testing, absorbable sutures are better than nonabsorbable sutures as seen in the figure. Here Prolene had only about 50% of the tensile strength of absorbable sutures, Vicryl and Maxon. It be concluded that braided, absorbable sutures such as Vicryl and Dexon Plus should be used only when enough healing can be expected within 2 weeks. If wound healing will likely take more than 2 weeks, one of the monofilament absorbable sutures (Maxon or PDS) or a nonabsorbable suture should be chosen. Also the researchers studied effects of hitches and knots; they found that, Maxon sutures demonstrated the best in-vitro knot security. But naturally addition of one hitch or six knots reduced the tensile strength of absorbable sutures by 30% to 35%. Also absorbable sutures show a considerable elongation before rupture. So we can say that absorbable sutures are initially

equal or superior to nonabsorbable sutures in terms of tensile strength but absorbed at variable rates by hydrolysis.

Absorbable surgical implants have two basic advantages. They show less chronic foreign body reactions associated with the implants and thus reduce undesirable complications, such as infection. Absorbable surgical implants could also stimulate the regeneration of the tissues. The apparent advantage of a degradable biomaterial is the obviation of surgical removal after it has fulfilled its mission. However, there is one major obstacle that prevents these bioabsorbable polymers from successful use as surgical implants in certain procedures: the lack of synchronization between the degradation of the synthetic absorbable polymers and the healing rate of certain tissues to be replaced or repaired. Thus, to achieve controlled degradation mechanism of absorbable implants is highly desirable. Four synthetic absorbable sutures are compared in table 4.

Other organs, like the bladder, contain fluids which make absorbable sutures disappear in only a few days, too early for the wound to heal. Inflammation caused by the foreign protein in absorbable sutures can amplify scarring, so if removable sutures are less antigenic it would represent a way to reduce scarring.

There are several materials used for non-absorbable sutures use in surgery. The most common is a natural fiber of silk, that represent a way to reduce scarring. Other non-absorbable sutures are made of artificial fibers, like polyester or nylon.

#### 4. Functional Requirements [10]

Different suture materials are associated with various degrees of tissue reaction. Significant inflammation reduces the resistance to infection and delays the onset of wound healing. The type of material and the suture size are the major factors that determine the reactions. Natural materials are absorbed by proteolysis. Synthetic materials are absorbed by hydrolysis, which minimizes such reaction.

#### NON-ABSORBABLE SUTURES [31]

Non-absorbable sutures are made of materials which are not metabolized by the body, and are used therefore either in skin wound closure, where the sutures can be removed after a few weeks, or in some inner tissues in which absorbable sutures are not adequate. This is the case for movement requires a suture which stays longer than three days.

Finally, there are also metal wires used in orthopedic surgery because of their strength and in some other tissues because of the metals outstanding tolerance by the body.

#### Biomaterials for Nonabsorbable Sutures [10]

**Table 6.** Characteristics of Nonabsorbable Sutures [10].

Properties	Silk	Nylon		Polyester	Polypropylene	Polybutester
		Monofilament	Multifilament			
Handling	Excellent	Poor	Fair-good	Good	Poor	Good
Knot security	Excellent	Poor	Fair-good	Good	Poor	Fair-good
Tensile strength	Low	High	High	High	Moderate	High
Coefficient of friction	High	Low	High	High	Very low	Very low
Memory	Low	High	Medium	Medium	High	Low
Tissue reactivity	High	Low	Moderate	Low-moderate	Low	Low
Uses	Sutures in mucosal tissues or conjunctive or intertriginous zones to elevate or retract tissues	Percutaneous sutures, buried sutures if prolonged dermal support is needed	Minimal use in dermatologic surgery	Minimal use in dermatologic surgery	Percutaneous sutures, buried sutures if prolonged dermal support is needed, running subcuticular closures	Percutaneous sutures, running subcuticular closures
Other	Black	Black, green or clear	-----	Green or clear	High plasticity, blue or clear	High elasticity, blue or clear

Nonabsorbable sutures are defined by their resistance to degradation by living tissues. They are most useful in percutaneous closures. Surgical steel, silk, cotton, and linen are natural materials (Table 5). Non absorbable suture characteristics of some materials are shown in table 5.

Synthetic multifilament sutures (eg, nylon, polyester) are used infrequently in dermatologic surgery. Nylon also is available as a monofilament suture and is commonly used in cutaneous procedures. Polypropylene and polybutester are also available. Table 6 shows nonabsorbable surgical sutures.

**a. Surgical Cotton [15]** – This is made of twisted, long, staple cotton fibers. Tensile strength is 50% in 6 months and 30-40% by 2 years. Surgical cotton is nonabsorbable and becomes encapsulated within body tissues.

**b. Surgical Linen [15]** – White twisted natural linen. High surface smoothness and excellent knot security. It has been used widely in surgical procedures for years and it is still well appreciated.

**c. Virgin Silk [5]** – Blue twisted multifilament. The manufacturing process ensures diameter uniformity, a smooth surface and the best treatment to achieve good knotting during micro and ophthalmic surgery.

**d. Surgical Silk [36]** – Black surgical silk braided on a twisted core to provide greater tensile strength. Smooth and uniform surface to facilitate handling achieved through silicone coating treatment and a new braiding technique.

**e. Nylon [33]** is a blue synthetic non-absorbable monofilament made of polyamide 6. Its advantages are: good knot-pull tensile strength, secure knot holding, smooth tissue passage, good tissue compatibility. It is useful for micro vascular, cataract, plastic, skin, nerve, fascia, and subcuticular.

**f. Polypropylene [35]** – The blue monofilament polypropylene (extruded form propylene polymer) is a flexible suture that allows for knot to self-block by flattening on itself. Extremely well tolerated. It is indicated for surgery procedures. Packaged flat to fully eliminate the thread's memory.

Its advantages are: high initial tensile strength, secure knot holding, optimal handling properties, smooth uniform surface allowing effortless passages through tissue, excellent tissue compatibility, unique penetration and breaking resistance of the D-tek needles.

It is used for: cataract, micro vascular, vascular, skin, subcuticular, plastic, cardiac, neurosurgical, gastro intestinal, fascia, obstetrical, gynecological and cornea.

**g. Polyester [32]** - is a white or green dyed non-absorbable coated braided synthetic suture made of polyethylene terephthalate (polyester). Green or white Teflon coated

braided polyester grants extraordinary smoothness, softness and non-thrombogenic features on the suture.

The suture thread is indicated for cardiovascular and vascular surgery procedures. Its advantages are: good knot-pull tensile strength, long-term tensile strength retention, excellent knot security and good tissue compatibility. It is indicated for: retinal, dacryocystorhinostomy, cardiac, vascular, gastro intestinal and fascia.

**h. Stainless Steel Wire [34]** - is a non-absorbable twisted thread made of corrosion-resistant steel. It has the following characteristics: exceptional tensile strength and excellent tissue compatibility. It is intended in tendon, fascia and sternum.

## MECHANICAL PROPERTIES [9, 11, 12, 13, 15, 19]

### Safety of Surgical Steel in our body

The bodies internal environment, is unique in its rapid degradation of many materials previously thought to be unaffected by highly caustic fluids.

The pH and ionic conditions within the human body is largely caused by the presence of Chloride Ions (0.11N, Interstitial Fluid). These Chloride ions have a highly corrosive effect particularly on Stainless Steels. Allergic reactions to Surgical Steel are rare, but this led to the adoption of either Titanium, or Titanium Stainless Steel alloys being used for Surgical implants i.e. hip replacements. Surgical steel is still in use for things like bone screws, pins, etc.

There have been some statements that the Nickel content of surgical steel (12%), can lead to allergic reactions, however, repeated tests have shown that surgical steel very rarely causes allergic reactions.

This is because the Nickel is bonded to the other elements of the Surgical Steel in such a way that the nickel is held within the crystalline structure of the steel, and the Chromium Di-oxide layer prevents any Nickel leaching into the body to cause allergic reactions. However, there are documented cases of allergic reactions to the nickel and chromium content of Surgical Steel.

The Nickel component of Surgical Steel is important for two reasons, firstly, Nickel resists corrosion far better than iron, thus improving Surgical Steel's ability to remain it's integrity within the bodies internal environment. Secondly,

Nickel is added to the Steel to increase it's strength and toughness, which is important for such body piercing jewellery as ball closure rings, which depend on the tension of the steel ring to hold the ball.

**Table 7.** Nonabsorbable Surgical Sutures [1].

Generic Name	Trade name	Manufacturer	Raw Material
<i>Natural Fibers</i>			
Surgical Cotton		Assut, SSC	Twisted natural cotton
Surgical linen		Assut, SSC	Twisted long-staple flax
Virgin Silk		Assut, SSC	Natural silk fibers spun by silkworms, twisted, untreated
Surgical Silk			Natural silk, twisted, silicone-impregnated
<i>Synthetic Sutures</i>			
Nylon	Dermalon	Davis & Geck	Polyamide 6, 6-monofil
	Ethicon	Ethicon	
	Sutron	SSC	
	Surgamid	Look	Polyamide 6,6-monofil or braided
	Supramid	SSC, Assut	
	Nurolon	-----	Polyamide 6-twisted fibers enclosed in a polyamide sheath
	Surgilon	Ethicon	Polyamide 6-braided
Prolene	Davis & Geck	Polyamide 6, 6-braided, silicone-coated	
Polypropylene	Surilene	Ethicon	Polypropylene-monofil
	Monolene	Davis & Geck	Polypropylene-monofil
Polyester	Dacron	SSC	Polyethylene terephthalate (PET) monofil
	Sterilene	Davis & Geck	PET, braided
	Mersilene	SSC	PET, braided
	Ti-Cron	Ethicon	PET, braided
	Astralen	Davis & Geck	PET, braided
	Ethibond	Assut	PET, braided, silicone-coated
	Polydek	Ethicon	PET, braided, silicone-coated
	Tevdek	Deknatel	PET, braided, polybutylate-coated
	Novafil	Deknatel	PET, braided, Teflon-coated
	-----	Davis & Geck	PET, braided, Teflon-impregnated
-----	-----	Polybusteter, monofilament	
<i>Metal Sutures</i>			
Stainless steel	-----	Ethicon	Stainless steel-monofil, twisted or braided
Surgical steel	-----	Assut	Stainless steel, twisted
Steel wire	-----	SSC	Stainless steel, mono and multifilament

A recent study was conducted on the nickel release from certain grades of Stainless Steel. The 316L Surgical Steel patch tests were conducted on 50 Nickel-sensitive patients. The patches were 1.5 centimetres in diameter, and a nickel plated patch was used as a benchmark. the 316L used in the test contained 11.29% nickel. 96% of the nickel-sensitive patients were intolerant to the nickel-plated steel, while no patients showed intolerance of the 316L Surgical Steel.

The classical allergic symptoms are, itching, redness, an intensely pruritic patch with vesicles and secretion of histamine, a clear fluid. In the rare case of an allergic reaction to Surgical Steel it can be replaced with Titanium

or Niobium which are totally inert. Be aware however that these metals require even more care in production and are much harder to produce to the standards required for implantation than Surgical Steel. Some reports in Body Piercing literature state that there is no such thing as "Surgical" Steel, However, there is a certain grade of steel which is used for implantation into the body, or "Surgical" purposes. So we can therefore use the term "Surgical Steel" even though that's not the exact scientific terminology, it's easier to use that term than to try to get the public used to all the other more complex classifications used for it.

316L is the most useful for body piercing jewellery, as it is fairly strong, easy to work with, and will not lose its corrosion resistance during manufacture. Type 316L (L = Low Carbon at 0.03%) 316LVM (Low carbon Vacuum Manufacture), and 317 are the only steels classified for use for surgical implantation.

It is one of the most important requirements of "Surgical" Steel, that it has the correct type of surface finish. The higher the degree of polish on the surface on the jewellery, the greater is its ability to resist corrosion, and as the bodies internal environment is unique in its corrosive abilities, it's highly important that proper body piercing jewellery has the ability to resist corrosion. No steel takes a more beautiful polish, and none holds it so well or so long as 316.

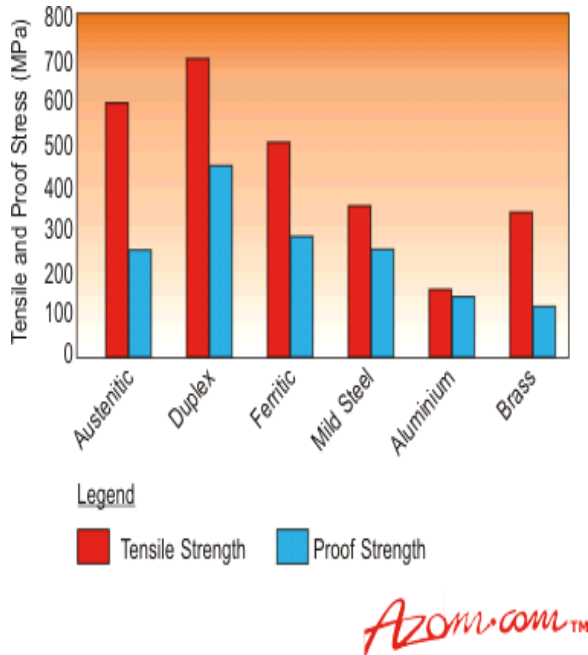
The quality of the jewellery's surface finish can significantly influence its ability to remain passive within the body, because the jewellery is placed within a wound, the interaction of the body and the metal occur on a cellular level.

At this level any small scratch on the surface can damage the very delicate process of scar formation, the jewellery is not static within the wound and this movement exacerbates any imperfections or scratches, tearing away the delicate tissue forming the Fistula around the jewellery.

Because of this the surface of the jewellery should possess no rough edges when examined under a microscope at 300 times magnification, it must be annealed and hand polished.

**Table 8.** Performance comparison of various suture materials [1].

Generic or trade name	Tensile strength	Tissue reactivity	Handling	Knot security	Memory
<i>Nonabsorbable Sutures</i>					
Cotton, twisted	Good	High	Good	Good	Poor
Silk, braided	Good	High	Poor	Good	High
Nylon, monofilament	High	Low	Good	Poor	Fair
Nylon, braided	High	Moderate	Poor	Fair	High
Polypropylene, monofil	Fair	Low	Fair	Poor	Low
Polybutester, monofil	High	Low	Good	Poor	Fair
Polyester (PET), braided	High	Moderate	Poor	Good	Fair
PET, braided, silicone-coated	High	Moderate	Good	Poor	Fair
PET, braided, polybutylate-coated	High	Moderate	Good	Good	Fair
PET, braided, Teflon-coated	High	Moderate	Poor	Good	Fair
PET, braided, Teflon-impregnated	High	Moderate	Poor	Poor	Poor
Stainless steel, mono-or multifil	High	Low	-----	Good	-----
<i>Absorbable Sutures</i>					
Collagen, plain and chromic	Poor	Moderate	Fair	Poor	Low
Coated vicryl	Good	Low	Good	Fair	Low
Dexon "S"	Good	Low	Fair	Good	Low
Dexon Plus (poloxamer 188-coated)	Good	Low	Good	Fair	Low
Dexon II (polycarbonate-coated)	Good	Low	Good	Good	Low
PDS	Good	Low	Poor	Poor	High
Maxon	Good	Low	Good	Good	Low



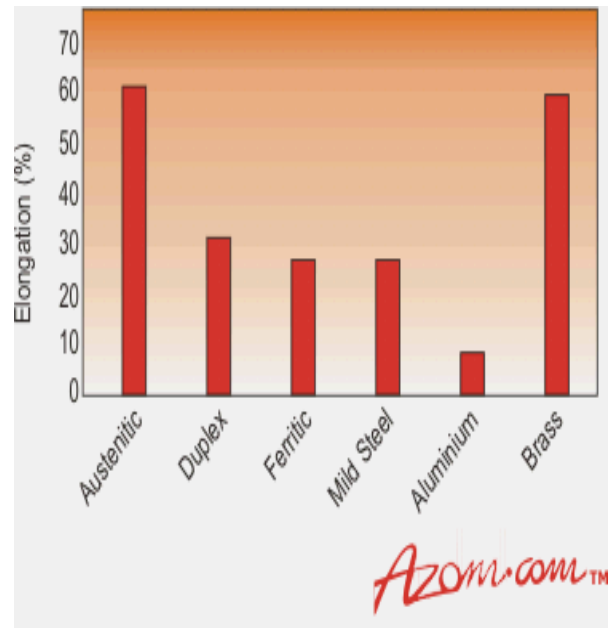
**Figure 2.** Typical Tensile Properties [11].

three times to a highly reflective lustre, under-polishing will be most evident on the inside of the ring and the tips, where polishing is most difficult. The standards of finish applicable for Surgical Steel are exactly the same for all other forms of body piercing jewellery, regardless of its shape or metallic composition.

Engineering design calculations are frequently made on yield criteria. The low yield strength of austenitic stainless steels may well mean that their design load cannot be higher than that of mild steel, despite the tensile strength being substantially higher. Design stresses for various grades and temperatures are given in Australian Standard AS1210 "Unfired Pressure Vessels". The other mechanical property of note is the ductility, usually measured by % elongation during a tensile test. This shows the amount of deformation a piece of metal will withstand before it fractures. Austenitic stainless steels have exceptionally high elongations, usually about 60-70% for annealed products, as shown in figure 3. It is the combination of high work hardening rate and high elongation that permits the severe fabrication operations which are routinely carried out, such as deep drawing of kitchen sinks and laundry troughs.

Hardness (measured by Brinell, Rockwell or Vickers machines) is another value for the strength of a material.

Hardness is usually defined as resistance to penetration, so these test machines measure the depth to which a very hard indenter is forced into a material under the action of a known force.



**Figure 3.** Typical elongations of annealed materials [11].

Each machine has a different shaped indenter and a different force application system, so conversion between hardness scales is not generally very accurate. Although conversion tables have been produced these conversions are only approximate, and should not be used to determine conformance to standards.

It is also sometimes convenient to do a hardness test and then convert the result to tensile strength. Although the conversions for carbon and low alloy steels are fairly reliable, those for stainless steels are much less so.

The mechanical properties of the majority of the stainless steel wire and bar products are generally sufficiently described by the tensile strength. These products require mechanical properties which are carefully chosen to enable the product to be fabricated into the finished component and also to withstand the loads which will be applied during service.

Spring wire has the highest tensile strength of the wire generally manufactured; it must be suitable for coiling into tension or compression springs without breaking during forming. However, such high tensile strengths would be completely unsuitable for forming or weaving applications because the wire would break on forming. Weaving wires are supplied in a variety of tensile strengths carefully chosen so that the finished woven screen will have adequate strength to withstand the service loads, and yet soft enough to be crimped and to be formed into the screen satisfactorily.

Mechanical properties of wire for fasteners are another example where a careful balance in mechanical properties is required. In this type of product the wire must be ductile enough to form a quite complex head but the wire must be hard enough so that the threads will not deform when the screw or bolt is assembled into the component.

Good examples are roofing bolts, wood screws and self-tapping screws; to achieve the mechanical properties required for such components requires careful consideration of the composition of the steel so that the work hardening rate will be sufficiently high to form hard threads on thread rolling and yet not so high as to prevent the head from being formed.

Ultimate elongation is important for any kind of material. It is nothing more than the amount you can stretch the sample before it breaks. Elastic elongation is the percent elongation you can reach without permanently deforming your sample. That is, how much can you stretch it, and still have the sample snap back to its original length once you release the stress on it. This is important if your material is an elastomer. Elastomers have to be able to stretch a long distance and still bounce back. Most of them can stretch from 500 to 1000 % elongation and return to their original lengths without any trouble.

Elastomers need to show high elastic elongation. But for some other types of materials, like plastics, it usually better that they not stretch or deform so easily. If we want to know how well a material resists deformation, we measure something called modulus. To measure tensile modulus, we do the same thing as we did to measure strength and ultimate elongation. This time we measure the stress we're exerting on the material, just like we did when we were measuring tensile strength. We slowly increase the amount of stress, and then we measure the elongation the sample undergoes at each stress level. We keep doing this until the sample breaks. Then we make plot of stress versus elongation, like in figure 6. There are times when the stress-strain curve is not nice and straight. For some polymers, especially flexible plastics, we get odd curves that look like in Figure 6. The slope is not constant as stress increases for polymers. The slope, that is the modulus, is changing with stress. In a case like this we usually that the initial slope as the modulus, as you can see in the stress-strain curve above.

In general, fibers have the highest tensile moduli, and elastomers have the lowest, and plastics have tensile moduli somewhere in between fibers and elastomers. Modulus is measured by calculating stress and dividing by elongation, and would be measured in units of stress divided by units of elongation.

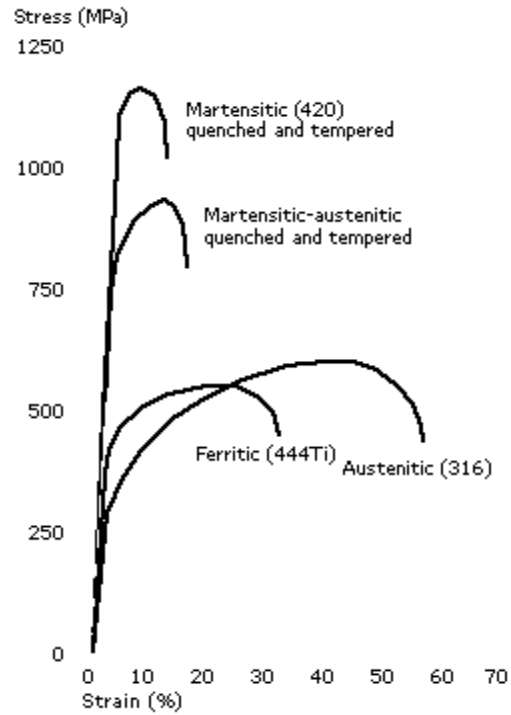


Figure 4. Stress vs Strain Curve [12].

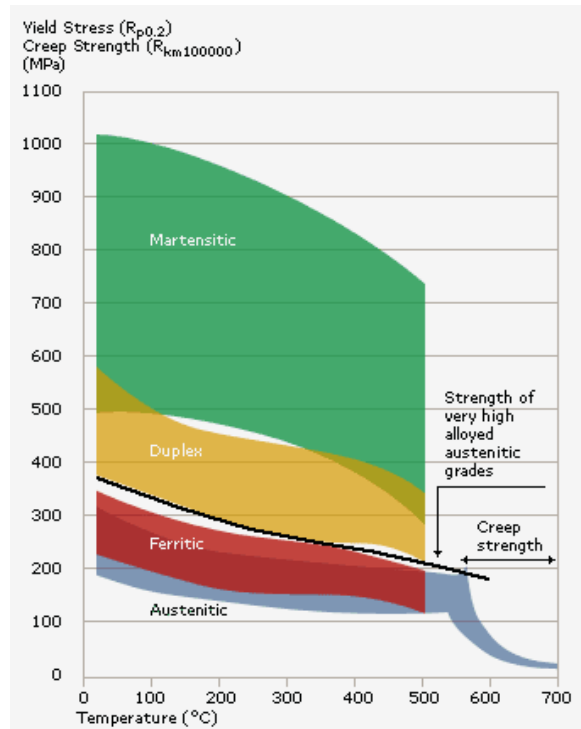
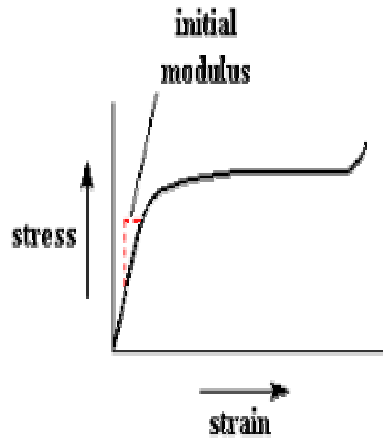


Figure 5. Yield strength and creep rupture strength curves [12].



After Odian, George; *Principles of Polymerization*, 3rd ed., J. Wiley, New York, 1991, p.34.

Figure 6. Stress Strain Curve ( Initial Modulus) [15].

But since elongation is dimensionless, it has no units by which we can divide. So modulus is expressed in the same units as strength, such as  $N/cm^2$ . In the next figure it's represented the Stress and Strain curve and also the initial modulus. Toughness is really a measure of the energy a sample can absorb before it breaks.

Think about it, if the height of the triangle in the plot is strength, and the base of the triangle is strain, then the area is proportional to strength times strain. Since strength is proportional to the force needed to break the sample, and strain is measured in units of distance (the distance the sample is stretched), then strength times strain is proportional to force times distance, and as we remember from physics, force times distance is energy.

How is toughness different from strength? From a physics point of view, the answer is that strength tells how much tell you what the practical differences are. Force is needed to break a sample, and toughness tells how much energy is needed to break a sample. But that doesn't really What is important is knowing that just because a material is strong, it isn't necessarily going to be tough as well. We'll look at some more graphs to show this. Take a look at the one below, the one with three plots, one blue, one red, and one and one pink (Figure 7). The blue plot is the stress-strain curve for a sample that is strong, but not tough. As you can see, it takes a lot of force to break this sample, but not much energy, as there isn't much area underneath the curve. Likewise, this sample can't stretch very far before it breaks. A material like this which is strong, but can't deform very much before it breaks is called brittle.

On the other hand, the red plot is a stress-strain curve for a sample that is both strong and tough. This material is not strong as the sample in the blue plot, but the area underneath its curve is a lot larger than the area under the blue sample's curve. So it can absorb a lot more energy than the blue sample can.

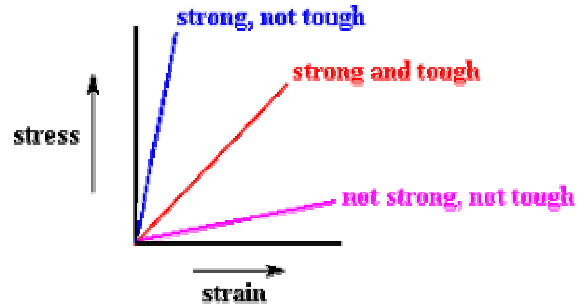
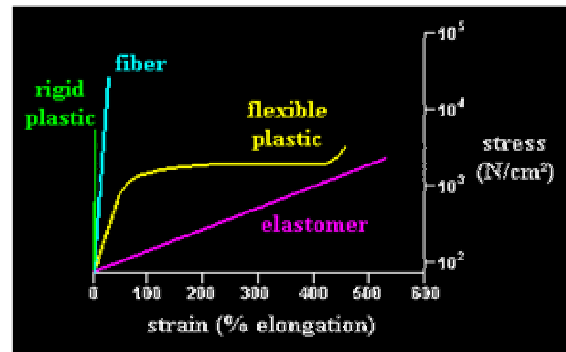


Figure 7. Stress Strain Curve [15].



After Odian, George; *Principles of Polymerization*, 3rd ed., J. Wiley, New York, 1991, p.34.

Figure 8. Stress versus Strain [15].

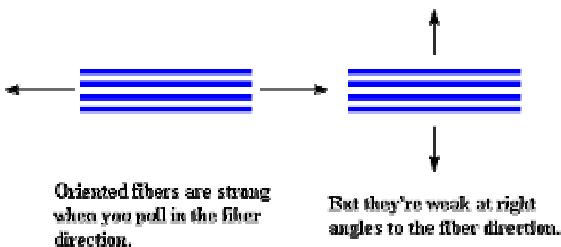
And why can the red sample absorb so much more energy than the blue plot? Take a look at the two. The red sample elongates a lot more before breaking than the red sample does. You see, deformation allows a sample to dissipate energy. If a sample can't deform, the energy won't be dissipated, and will cause the sample to break.

In real life, we usually want materials to be tough and strong. Ideally, it would be nice to have a material that would not bend or break, but this is the real world. The designer has to make trade-offs. Take a look at the plots again. The blue sample has a much higher modulus than the red sample. While it's good for materials in a lot of applications to have high moduli and resist deformation, in the real world it's a lot better for a material to bend than to break, and if bending, stretching or deforming in some other way prevents the material from breaking, all the better. So when we design new polymers, or new .

Figure 8, compares typical stress-strain curves for different kinds of polymers. It can be observed in the plot that a rigid

**Table 9.** Properties of 316 grade stainless steels [13].

<b>Grade</b>	316	316L	316H
<b>Tensile Strain (MPa) min</b>	515	485	515
<b>Yield Strain .02% proof (MPa)j min</b>	205	170	205
<b>Elongation (50% in 50 mm) min</b>	40	40	40
<b>Hardness Rockwell B (HRB) max</b>	95	95	95
<b>Tensile Strain (MPa) min</b>	515	485	515
<b>Yield Strain .02% proof (MPa) min</b>	205	170	205
<b>Elongation (50% in 50 mm) min</b>	40	40	40
<b>Hardness Rockwell B (HRB) max</b>	95	95	95
<b>Grade</b>	316/LH	316 L	----
<b>Density (kg/m<sup>3</sup>)</b>	8000	-----	----
<b>Elastic Modulus (GPa)</b>	193	-----	----
<b>Coefficient of thermal expansion (µm/m°C)</b>	0-100	15.9	---



composites, we often sacrifice a little bit of strength in order to make the material tougher.

**Figure 9.** Direction of the Fibers and Good Tensile Relation [15].

plastics such as polystyrene or polycarbonate can withstand a good deal of stress, but they would not withstand much elongation before breaking. There is not much area under the stress-strain curve at all. So we say that materials like this are strong, but not very tough. Also, the slope of the plot is very steep, which means that it takes a lot of force to deform a rigid plastic. (I suppose that's what it means to be rigid, now doesn't it?) So it's easy to see that rigid plastics have high moduli. In short, a rigid plastics tend to be strong, resist deformation, but it they tend not to be very tough, that is, it's they're brittle.

Flexible plastics like polyethylene and polypropylene are different from rigid plastics in some ways. For example they don't resist deformation as well, but they tend not to break. Of course, the ability to deform is what keeps them from breaking. Initial modulus is high, that is it will resist deformation for a while, but if enough stress is put on a

flexible plastic, it will eventually deform. You can try this at home with a piece of a plastic bag. If you try to stretch it, it will be very hard at first, but once you've stretched it far enough it will give way and stretch easily. The bottom line is that flexible plastics may not be as strong as rigid ones, but they are a lot tougher.

It is possible to alter the stress-strain behavior of a plastic with additives called plasticizers. A plasticizer is a small molecule that makes plastics more flexible. For example, without plasticizers, poly (vinyl chloride), or PVC for short, is a rigid plastic. Rigid unplasticized PVC is used for water pipes. But with plasticizers, PVC can be made flexible enough to use to make things like inflatable swimming pool toys.

Fibers like Kevlar™, carbon fiber and nylon tend to have stress-strain curves like the aqua-colored plot in the graph above. Like the rigid plastics, they are more strong than tough, and don't deform very much under tensile stress. But when strength is what you need, fibers have plenty of it. They are much stronger than plastics, even the rigid ones, and some polymeric fibers, like Kevlar™, carbon fiber and ultra-high molecular weight polyethylene have better tensile strength than steel.

Elastomers like polyisoprene, polybutadiene and polyisobutylene have completely different mechanical behavior from the other types of materials. Take a look at the pink plot in the graph above. Elastomers have very low moduli. You can see this from the very gentle slope of the pink plot, but you probably knew this already. You already knew that it is easy to stretch or bend a piece of rubber. If elastomers didn't have low moduli, they wouldn't be very good elastomers, now would they?

But it takes more than just low modulus to make a polymer an elastomer. Being easily stretched is not much use unless the material can bounce back to its original size and shape once the stress is released. Rubber bands would be useless if they just stretched and didn't bounce back. Of course,

elastomers do bounce back, and that's what makes them so amazing. They have not just high elongation, but high reversible elongation.

The compressional properties or flexural properties can be completely different. For example, fibers have very high tensile strength and good flexural strength as well, but they usually have terrible compressional strength. They also only have good tensile strength in the direction of the fibers.

## RECOMMENDATIONS

Biomaterials that we use for sutures has changed a lot since their beginnings. Everyday people find new and best materials to use in surgeries. We need to continue working to find better materials that those we know today, with better quality, less defects and adverse effects

## SUMMARY

Human body is very delicate and important. When surgeries are needed to improve our health is very important to select the kind of suture that satisfies all the requirements. Because exists one type of suture perfect for every need. Today we know a lot of biomaterials to select, but always is important to first think in the biocompatibility.

## ACKNOWLEDGEMENTS

We want to thank Dr. Megh R. Goyal for his help and guidance.

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## GLOSSARY

**Absorbable sutures** are made of materials which are metabolized inside the body after around three weeks, and then disappear. They are used therefore in many of the inner tissues of the body. In most cases, three weeks is sufficient for the wound to close firmly.

**Atraumatic sutures** include a needle on each thread. The advantages of having the needle mounted on the suture are several. The doctor or the nurse do not have to spend time threading the suture on the needle. More important, yet, is the fact that needle and thread form a single, even body. In case of the traumatic suture, the thread comes out of the needle's hole on both sides.

**Non absorbable sutures** are made of materials which are not metabolized by the body, and are used therefore either on skin wound closure, where the sutures can be removed after a few weeks, or in some inner tissues in which absorbable sutures are not adequate.

**Nylon:** An abrasion resistant thermoplastic with good chemical resistance.

**Polymers:** Compounds of very high molecular weights that are made up of a large number of simple molecules which have reacted with one another.

**Silk:** a fabric made from the fine threads produced by certain insect larvae.

**Stainless Steel:** A highly corrosion resistant steel alloy containing either chromium, nickel, or copper.

**Suture:** Sutures, or stitches, are materials used to close a wound. They are used in an attempt to improve and speed healing.

**Traumatic sutures** are those which are supplied to the hospital plain, i.e., the suture thread with nothing else. The needle required to use the suture is a separate item. The suture must be thread as it is done when sewing at home.

## APPENDIX I: NUMERICAL EXERCISES

### TENSION, COMPRESSION, AND SHEAR

A stainless steel bar with a diameter  $d=23\text{mm}$  is subjected to a tensile load  $P=30\text{N}$ . The original length of the bar is  $80\text{mm}$

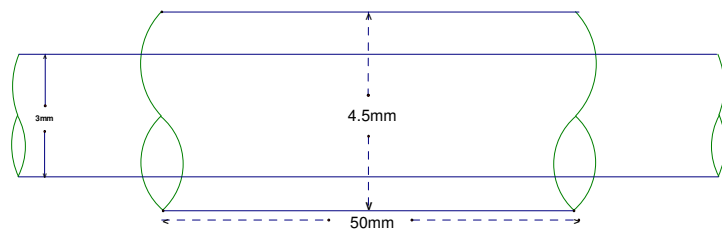
- What is the elongation of the bar if  $E=15\text{Pa}$ ?
- What is the stress in the bar?

#### SOLUTION:

$$\text{a) } \delta = \frac{PL}{AE} = \frac{(30)(0.080)}{15\left(\frac{\pi}{4}\right)(0.023)^2} = 385.1 \text{ m}$$

$$\text{b) } \sigma = \frac{P}{A} = \frac{(30)}{\left(\frac{\pi}{4}\right)(0.023)^2} = 72206.4 \text{ Pa}$$

## AXIALLY LOADED MEMBERS



A cylindrical surgical instrument consists of a Nylon core surrounded by a 316 stainless steel shell. The instrument is 50 mm long with core diameter of 2 mm, inner shell diameter of 3 mm and outer shell diameter of 4.5 mm. The modulus of elasticity  $E$  of nylon is  $E = 2.3 \text{ GPa}$  (reference in Appendix H, page 913 of the text book Mechanics of Materials) and for 316 stainless steel is 193 GPa. If a load  $P$  compresses the core and shell of the instrument at which force will compress it by .005 mm?

### SOLUTION:

Given:  $\delta = 0.05 \text{ mm}$

$E_1 =$  modulus of elasticity of nylon = 2.3 GPa

$d_1 =$  diameter of nylon core = 2 mm

$$Area_1 = \frac{\pi}{4} (2 \text{ mm})^2 = 3.1416 \text{ mm}^2$$

$E_2 =$  modulus of elasticity of 316 stainless steel = 193 GPa

$d_{2a} =$  inner diameter of 316 stainless steel shell = 3 mm

$d_{2b} =$  outer diameter of 316 stainless steel shell = 4.5 mm

$$Area_2 = \frac{\pi}{4} (4.5 \text{ mm} - 3 \text{ mm})^2 = 1.7671 \text{ mm}^2$$

$$P = \frac{\delta}{L} (E_1 A_1 + E_2 A_2)$$

$$= \left( \frac{0.05}{50} \right) (2.3 \cdot [3.1416] + 193 [1.7671])$$

$$= 0.3483 \text{ KN}$$

Find the  $P_{allow}$  of stainless steel if the allowable stress is 205 Mpa

$$P_{allow} = \left( \frac{\delta}{E} \right) (E_1 A_1 + E_2 A_2)$$

$$= 345.276 \left( \frac{205}{193} \right)$$

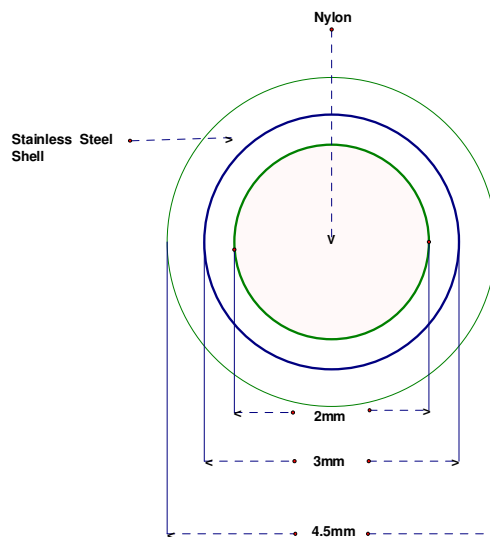
$$= 392.93 \text{ KN}$$

Find the  $P_{allow}$  of nylon if the allowable stress is 3.1 Mpa

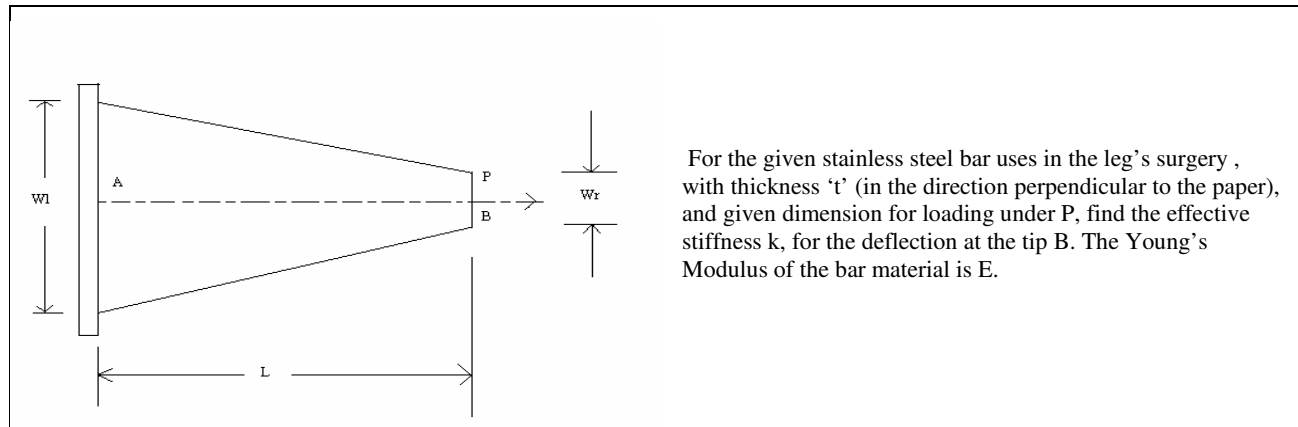
$$P_{allow} = 348.276 \left( \frac{3.1}{2.3} \right) = 469.415 \text{ KN}$$

Find  $P_{max}$  the maximum permissible load  $P$

$$P_{max} = 469.415 \text{ KN}$$



## AXIALLY LOADED MEMBERS



### SOLUTION:

- To find stiffness at point 'B', determine deflection of point B.
- We Know that ;  $E\epsilon = \partial U_x / \partial x$  , therefore

$$\partial = U_x^B = \int_0^L \epsilon dx$$

$$U_x^B = \int_0^L \left( \frac{\sigma}{E} \right) dx = \int_0^L \left( \frac{P}{AE} \right) dx$$

For this section, the area is given by;

$$A(x) = t \left[ \left( \frac{W_r - W_l}{L} \right) x + W_l \right]$$

$$\text{Also } U_x^B = \int_0^L \frac{P}{Et \left[ \left( \frac{W_r - W_l}{L} \right) x + W_l \right]} dx$$

For the case of  $W_r = W_l$ , the integration breaks down and this must be solved at this step;

$$U_x^B = \int_0^L \frac{P}{Et[W_l]} dx = \frac{PL}{EtW_l} \quad \text{Also} \quad K = \frac{P}{U_x^B} = \frac{EtW_l}{L}$$

For  $W_l = W_b$

However, if  $W_l \neq W_b$ , the integration must continue...

$$U_x^B(x) = \int_0^L \frac{P}{Et \left[ \frac{(W_r - W_l)x}{L} + W_l \right]} dx = \frac{PL}{Et} \int_0^L \frac{1}{(W_r - W_l)x + W_l L} dx$$

Substitution method;

Let  $V = (W_r - W_l)x + W_l L$ , then  $dv = (W_r - W_l)dx$

$$\text{Also } U_x^B(x) = \frac{PL}{Et} \int_0^L \frac{dv}{V} \cdot \frac{1}{(Wr - Wl)} = \frac{PL}{Et(Wr - Wl)} \ln V \text{ from 0 to L}$$

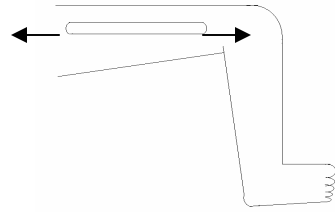
$$U_x^B(x) = \frac{PL}{Et(Wr - Wl)} \ln[(Wr - Wl)x + WlL] \text{ from 0 to L}$$

$$U_x^B(x) = \frac{PL}{Et(Wr - Wl)} \ln\left[\frac{Wr.L}{Wl.L}\right]$$

$$U_x^B(x) = \frac{PL}{Et(Wr - Wl)} \ln\left[\frac{Wr}{Wl}\right]$$

$$K = \frac{P}{U_x^B(x)} = \frac{Et(Wr - Wl)}{L \cdot \ln\left(\frac{Wr}{Wl}\right)} \text{ for all } Wr \neq Wl$$

## TORSION



A solid stainless steel replacement leg bar of circular crosssection has a diameter  $d=1.5$  in and a length  $L=12$  in and a shear modulus of elasticity  $G=10.6 \times 10^6$  psi . The leg replacement is subjected to torque  $T$  acting at the ends.

a) If a torque have a magnitude of  $T=250$  lb-in. What is the maximum shear stress in the bar ? What is the angle of twist?

## SOLUTION:



$$\tau_{\max} = \frac{16 T}{\pi d^3} = \frac{16 (250 \text{ lb-in})}{\pi (1.5 \text{ in})^3} = 377.27 \text{ psi}$$

$$\Phi = \frac{TL}{EI_p} = \frac{(250 \text{ lb-in})(12 \text{ in})}{(10.6 \times 10^6 \text{ psi})(.4970 \text{ in}^4)} = 0.00057 \text{ rad} = 0.033 \text{ degree}$$

