

A Complete Review of Wound Closure

by

Sima J. Doshi

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

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Abstract

This thesis is a complete review of all existing wound healing and wound closure techniques. A brief history of wound healing is first accounted. The biological basis of wound healing is explained to lay a foundation for the understanding of wound healing and closure techniques. Procedures and products for wound closure are presented and described. Emphasis is placed on dressings, suturing, and mechanical wound closure device techniques. Finally, wound healing and closure techniques under development will be presented.

Thesis Supervisor: Ernesto E. Blanco

Title: Professor

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Contents

1	A History of Wound Closure	9
1.1	Southern Mesopotamia, 3100 - 2100 B.C.	10
1.2	Egypt, 2900 - 1000 B.C.	12
1.3	Greece, 500 - 300 B.C.	12
1.4	China, 1050 - 220 B.C.	13
1.5	India, 300 - 0 B.C.	14
1.6	Rome, 20 - 80 A.D.	14
1.7	Europe, 1000 - 1900 A.D.	16
2	Wound Healing	20
2.1	Infection of Wounds	21
2.2	The Biology of Repair	22
2.2.1	First Intention	23
2.2.2	Second Intention	25
2.2.3	Third Intention	26
2.3	Factors Influencing Wound Healing	27
2.3.1	Systemic Factors	28
2.3.2	Local Factors	29
2.4	Growth Factors	31
2.4.1	Summary of Growth Factors	32
2.4.2	Repair With Growth Factors	34
3	Dressings	36
3.1	Functions of Wound Dressings	37
3.2	Types of Natural Dressings	38

3.2.1	The Contact Layer	38
3.2.2	The Intermediate Layer	42
3.2.3	The Outer Wrap	42
3.3	Synthetic Dressings	43
3.4	Biologic Dressings	45
3.4.1	Skin Grafts and Flaps	47
4	Sutures and Suturing	51
4.1	Suture Materials	52
4.1.1	Absorbable Sutures	53
4.1.2	Nonabsorbable Sutures	57
4.1.3	A Comparison of Sutures	61
4.2	Suturing Techniques	61
4.2.1	Ligatures	61
4.2.2	Primary Suture Line	63
4.2.3	Secondary Suture Line	65
4.2.4	Placement of Stitches	67
4.2.5	Knot Security and Knot Tying	67
4.2.6	Cutting Sutures	70
4.2.7	Suture Removal	70
4.3	Suture Selection	70
4.3.1	Sutures Needed in Abdominal Surgery	70
4.3.2	Layered Closure	73
4.3.3	Sutures Needed in Other Body Tissues	77
4.3.4	Summary of Principles for Suture Selection	80
5	Mechanical Wound Closure Devices	82
5.1	Ligating Clips	82
5.1.1	Nonabsorbable Ligating Clips	83
5.1.2	Absorbable Ligating Clips	86
5.2	Surgical Staplers	86
5.2.1	Skin Staplers	88
5.2.2	Intraluminal Staplers	89

5.2.3	Linear Staplers	91
6	Miscellaneous Products and Methods for Wound CLOSure	93
6.1	Skin Closure Tapes	93
6.2	Surgical Meshes	96
6.3	Tapes	98
6.4	Hemostatic Agents	99
6.5	Looped Sutures	99
6.6	Lasers	99
6.7	Electrocautery	100
6.8	Heat Lamp Therapy	100
6.9	Wound Irrigation Therapy	100
6.10	Topical Oxygen Therapy	101
6.11	Topical Antibiotic Therapy	101
6.12	Aloe	102
6.13	Honey/Sugar	102
6.14	Sugar and Povidone-Iodine Preparations	102
7	New and Future Technologies, An Overview	103

List of Figures

1-1	Simple Fibulae. From a French Manual of 1858.	15
1-2	<i>The use of the cautery; woodcut from Albucasis.</i> From Chirurgicorm Omnium, 1532 in the Wellcome Museum Library.	17
1-3	A Paré-Style Ligature, c. 1640. 10 cm. From Germanisches Nationalmuseum, Nuremberg.	18
1-4	Garot Tourniquets, c. 1800. From Musée d'Histoire de la Médecine, Paris; Cliché Assistance Publique	19
2-1	The Infection Rates of Five Classes of Wounds.	23
2-2	First Intention Wound Healing Time Scale	25
2-3	Closed vs. Open Wounds	26
2-4	Optimal Time For Delayed Closure	27
2-5	The Wound Healing Process	35
3-1	A Three-Layer Dressing	39
3-2	Dressings Used for Debridement	40
3-3	Nonabsorbant Dressings	41
3-4	Thin vs. Thick Split-Thickness Grafts	48
3-5	Types of Flaps for Wound Construction. A. Random Skin Flap. B. Axial Skin Flap. C. Myocutaneous Flap.	50
4-1	Breaking Strength Retention and Absorption Profiles of Ethicon Absorbable Sutures	54
4-2	Loss of Strength and Volume of Absorbable Sutures	54
4-3	Suture Strength of Various Suture Materials vs. Suture Diameter	62
4-4	Tissue Reaction of Various Suture Materials vs. Suture Mass	62

4-5	Continuous vs. Interrupted Sutures	64
4-6	Common Suturing Techniques	66
4-7	The Configuration of Surgical Knots	69
4-8	Layers of the Abdominal Wall	73
4-9	Retention Sutures With Bolsters	76
5-1	The Deforming of a Nonabsorbable Ligation Clip upon Closure	84
5-2	Nonabsorbable Ligation Clip Appliers	85
5-3	Nonabsorbable Ligation Clip Cartridges	85
5-4	Absorbable Ligation Clips	87
5-5	Skin Staplers	89
5-6	Intraluminal Stapler	90
5-7	Adjustable Staple Height	90
5-8	Linear Stapler	91
5-9	Flexible Linear Stapler	92
6-1	Application of Skin Closure Tapes	95
6-2	Polypropylene Mesh	98
7-1	Design of an Ophthalmic Stapler	107
7-2	A Cartridge of Microstaples	108
7-3	A Comparison of Sutures and Microstaples in the Eye	108

Chapter 1

A History of Wound Closure

Long before the birth of experimental medicine, wounds functioned as natural experiments. They were treated using various methods, and the better methods and dressings won out in the long run. There has been a constant battle between man and bacteria, and the wound was the first medical library.

Wounds have been evident long before the existence of man or mammals. The existence of wounds can be verified by traces left in fossils from millions of years ago. For example, evidence of wounds can be found in the fossils of ammonites which existed about 200 million years ago, by the appearance of imperfections in their otherwise precise spiral shells.¹

Moving forward in history to our most likely ancestor, *Australopithecus Africanus*, living about five million years ago, we find what is commonly referred to as the “first wound”. The skulls of these man-apes were found to have peculiar double depressions, which were determined by Raymond Dart to be caused by attacks with weapons.²

Even a million years ago, a wound implied the same medical problems as they do now: mechanical disruption, bleeding, and infection. Natural processes can deal with all three of these problems, but man can help, even using simple methods. Bandages are probably as old as clothing, though the oldest known bandages were found in Egypt and even these were quite advanced because they were applied with splints. The notion of adhesive tape, although seeming quite modern, may be over four thousand years old, because “stickiness” is an old concept through the use of resin. The use of clips can also be documented in

¹Guido Majno, *The Healing Hand - Man and Wound in the Ancient World* (Cambridge, Massachusetts: Harvard University Press, 1975) 6.

²Majno 6.

ancient Hindu medicine through the use of insect mandibles as clips.³

The act of sewing is probably older than the species *Homo sapiens* because Neanderthal man wore clothing, however, the application of sewing to wounds is not evidenced often. This may be due to failed attempts because suturing is very prone to infection and may actually prevent the wound from healing. Clearcut evidence of suturing can be found much later in the classical writings of India and Greece.⁴

The problem of hemorrhage was solved even later than suturing. The main facts about bleeding and stopping bleeding were not easily grasped by man. Minor bleeding can be checked by the use of bandaging. However, many of the thousands of materials stuffed into wounds over the centuries did not help blood clotting. The most effective means to stop bleeding developed by primitive people is the cautery, which dates as far back as 3000 B.C. However, wounds to any major vessel meant bleeding to death until the recent centuries. By the time tourniquets were used regularly, people were shooting guns.⁵

To witness the development of wound closure methods, we will now examine the ancient civilizations individually. Since these civilizations were fairly isolated, the same methods independently developed at different times. When contact between civilizations occurred, the methods that worked were adopted by other civilizations, and we see a sudden appearance of certain procedures in those civilizations. We will begin with the civilizations that existed in southern Mesopotamia at approximately 3100 B.C.

1.1 Southern Mesopotamia, 3100 - 2100 B.C.

Several groups of people lived in southern Mesopotamia at around 3100 B.C., all of whom spoke Akkadian dialects. These groups included the Sumerians, the Assyrians, the Babylonians, and the Chaldeans.⁶ The world's oldest medical manuscript is a small clay tablet written in the Sumerian dialect around 2100 B.C. Therefore, a thousand years had passed before any medical knowledge was written down. Instead, medical practices were passed from generation to generation through oral transmission. Mesopotamians could receive treatment from two sources that were equally valid in their eyes; they could either receive

³Majno 11.

⁴Majno 14.

⁵Majno 15.

⁶Majno 34.

primitive first aid from a physician or receive sorcery from a sorcerer.⁷ We will focus on the primitive first aid given by the Mesopotamian physician, or in other words, the *asu*.

According to the *asu*, there were three healing gestures for wounds: washing, making plasters, and bandaging. In the Sumerian medical manuscript, there were fifteen prescriptions for wounds, twelve of which were for external use, and eight of which were plaster ingredients. These plasters included ingredients such as herbs, beer, milk, fruits, oil, and of course the old fashioned mud plaster.⁸ It is important to note that some of these ingredients may have been beneficial. For example, some plant extracts contain antibacterial substances, and some resins of trees are also antiseptic.⁹

The basic procedure for treating most wounds, however, was approximately the same. The diseased part is first washed with beer and hot water. Sometimes a form of liquid soap was used for the washing. The soap was made by heating resin or fat with alkali, obtained by burning certain plants. Next, the first rubbing was applied. This rubbing was a mixture including salt and mustard. This was probably applied to produce a stinging sensation, which would make the patient believe that the medicine was working. Then the plaster was applied, and the type of plaster depended on the type of wound.¹⁰ Finally the dressing, fine linen washed in water and soaked in oil, was applied. Sesame oil was used in Mesopotamia, olive oil in Palestine. The purpose of the oil was to prevent the bandage from sticking to the wound, and also to prevent bacterial growth.¹¹ Even the Bible makes reference to this method of treatment:

O sinful nation, people loaded with iniquity... from head to foot there is not a sound spot in you - nothing but bruises and weals and raw wounds which have not felt compress or bandage or soothing oil.¹²

The *asu* however, knew little about anatomy, and nothing about sutures, cauteries, or ligatures of bleeding vessels. The extent of his knowledge was different concoctions of plasters. We will now look to the ancient Egyptian civilizations for more clues about the development of wound closure methods.

⁷Majno 38-39.

⁸Majno 46.

⁹Majno 61.

¹⁰Majno 48-49.

¹¹Majno 52-53.

¹²Majno 53.

1.2 Egypt, 2900 - 1000 B.C.

The ancient Egyptians seemed to have been much more advanced in the art of wound closure than the Mesopotamians. The Egyptians did use bandaging, just as the Mesopotamians, but we also see the first instances of several modern day methods of wound closure. The *Smith Papyrus* which was written around 1650 B.C., documents some of the medical procedures very well. The problem however is the translations. In some cases, one translation documents the use of stitches, while another translation, for the same cases, states that they were clamps, not stitches, since no surgical suture has been preserved in mummies. The oldest known stitches in human flesh were done by an embalmer, after the person had died. However, either case is an improvement in medical practices. It could even be that both translations were correct; among primitive people one of the earliest wound-closing devices is a combination of a clamp and a suture: a thorn or needle is stuck through both lips of the wound, and the protruding ends are tied together by a thread placed as a figure eight.¹³

A second method of wound closure known to Egyptians, that demonstrated an advance, was adhesive strips. The adhesives used by the Egyptians were gum from acacia trees and several types of resin. Also, the first recorded hemostasis achieved by burning is recorded in the *Smith Papyrus*. One interesting point however, is that there is no mention in the *Smith Papyrus* of washing the wound before treatment, and this may actually have been a step backwards.¹⁴

1.3 Greece, 500 - 300 B.C.

The ancient Greeks, during the time of Hippocrates had a wide array of wound closure methods. The Greeks were skilled in bandaging, and the skill of applying bandages was transformed into an elegant art.¹⁵ The Greeks also used plasters in a few cases, with ingredients such as vinegar, flour, wheat, gum, resin, grease, oil, zinc oxide, and celery, that were held in place with cloth.¹⁶ The basic procedure of bandaging was as follows: The wound was sponged with hot vinegar. Then either sweet wine was applied or the wound was

¹³ Majno 92-93.

¹⁴ Majno 94-95.

¹⁵ Majno 148.

¹⁶ Majno 168-176.

burned with a caustic. Therefore, the Greeks understood cauterization principles. Then a pad of wool is dipped in enHEME, a mixture of copper acetate, copper oxide, lead oxide, Alum, myrrh, frankincense, gall nuts, vine flowers and grease of wool. This mixture includes several ingredients that kill bacteria, and several ingredients for good scent, but the grease is an unclean ingredient. Finally tight pressure is applied from a tight bandage around the wound.¹⁷

The ancient Greeks knew the main principle of the tourniquet and also knew its danger, gangrene. However, they did not know how to perform the ligation of bleeding vessels, so the discovery of the tourniquet was too early, and was lost in history until it was rediscovered in the mid-1500s A.D. by Ambroise Paré.

The ancient Greeks also used suturing for cuts. A bronze needle with thread was used for the actual suturing, and the suture was covered with a mixture of copper oxide and honey, over which a double pad of cloth soaked in wine was applied, and finally a slice of clean, dry sponge and a handful of leaves was placed to apply pressure.¹⁸ The consistent use of wine and vinegar by the Greeks is evidence that they understood the antiseptic nature of these materials.

1.4 China, 1050 - 220 B.C.

China, from 1030 - 221 B.C. was under the court of the Chou. The main medical text of this dynasty, *Huang Ti Nei Ching*, was written sometime between 479 - 300 B.C., and is therefore contemporary to the Hippocratic collection.¹⁹ The ancient Chinese ascribed a low status to surgery. They saw the wound as an imbalance between yin and yang, two complementary forces that exist in a person.²⁰

The ancient Chinese used two methods to correct the imbalance. The first method was acupuncture. The skin would be pierced with needles in one to several of 365 possible points, depending on the type of imbalance, astrology and other factors. The purpose of this is to release the energy from the wound.²¹

The second method to bring back the balance between yin and yang was the use of

¹⁷ Majno 154.

¹⁸ Majno 161.

¹⁹ Majno 240.

²⁰ Majno 247.

²¹ Majno 248.

moxa. Moxa is the burning of the wound with small lumps of smoldering material. Two to three pinches of powdered leaves of *Artemisa vulgaris* or *alba*, a type of wormwood, was rolled into a little cone, and placed on the patient at precise spots. The tip of the cone was set on fire, and the cone was allowed to smolder until nothing but ashes was left. This is a type of cautery treatment.²²

The use of sutures is present during the second century B.C. but because of the low status of surgery, is not well documented until the second century A.D. by the surgeon Hua T'o.²³

1.5 India, 300 - 0 B.C.

Four sacred books, called *Vedas*, were written in Sanskrit in ancient times, and the fourth *Veda*, *Atharra Veda*, was about a system of medicine. It talked about plaster made of honey-butter paste and clean linen bandages just as the other ancient civilizations. By the last centuries of B.C. however, during the kingdom of Magadha under King Ashoka, many modern treatments for wound closure were being used.²⁴

The first mentioning of the tourniquet in clinical practice was by the doctor Sushruta. The tourniquet first developed in India, to prevent venous blood flow in the case of snake bites. This is because, they wanted to prevent the poison from returning to the heart.²⁵ The use of sutures of cotton, Chinese silk, hemp, linen, and plaited horse hair was also documented by Sushruta, as was the use of cautery to stop bleeding.²⁶

One interesting innovation was the use of clamps made of the mandibles of ants. The mandibles grasp the two edges of the wound and bring them together. The body is severed from the head and removed. The head and mandibles remain as a ligature.²⁷

1.6 Rome, 20 - 80 A.D.

Rome, during the first century A.D. was at its height. A prominent physician Cornelius Celsus (14 - 37 A.D.) documented several methods of wound closure. These included the

²²Majno 249.

²³Majno 253.

²⁴Majno 262-263.

²⁵Majno 283.

²⁶Majno 302.

²⁷Majno 304.

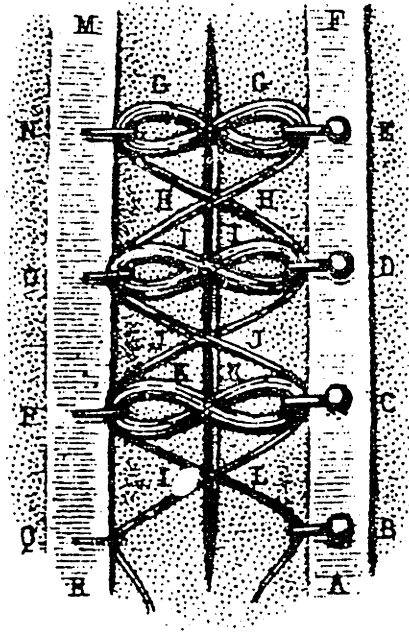


Figure 1-1: Simple Fibulae. From a French Manual of 1858.

tying of blood vessels, the burning of wounds with a red hot iron, the stitching of wounds, if the wound was in a “soft part”, using women’s hair for fine stitchwork, and the use of metal pins, if the wound is in the flesh, gapes, or its margins are not easily drawn together. These metal pins, called fibulae, are inserted to draw the margins of the wound together to some extent and render the subsequent scar less broad. Fibulae used for sutures, as shown in Figure 1-1²⁸, were the simplest, and lasted until recently for the correction of harelip.²⁹

Pliny (23 - 79 A.D.), who also lived in this period, wrote books on medicine, and talked of a plant called ephedron, that stops hemorrhage. This is an accurate description of the plant *Ephedria* and its product ephedrine which actually does stop bleeding. Ephedrine was used in China for over 5000 years, although not documented, before being introduced to Western medicine in 1924 by American physician Carl Frederic Schmidt, who had worked in Peking Union Medical College, and found it used there.³⁰

²⁸Majno 366.

²⁹Majno 362-367.

³⁰Majno 349.

1.7 Europe, 1000 - 1900 A.D.

After approximately 150 A.D., the history of the wound grinded to a halt for about a thousand years. Europe sank into the Dark Ages; Indian surgery declined; even in China, where science advanced, surgery made no progress.³¹ Many of the techniques known to the great ancient civilizations were lost and had to be rediscovered during the middle ages and the renaissance of Europe.

For example, two Arabian physicians of the tenth century reestablished the use of the red hot cautery. However, the function of the cautery as a means of stopping bleeding that the ancients had discovered, was not understood. Instead the cautery was used as a cure-all for afflictions such as epilepsy, headache, toothache, pilis, pleuisy, dropsy, melancholia, etc. William Clowes, surgeon to Queen Elizabeth was very fond of using the cautery. Most of the cauteries were made of iron, with a few of gold, and they came in a large variety of sizes and geometric patterns.³² Figure 1-2³³ shows several cautery shapes and how the cautery was used.

The use of the cautery later lost popularity, and passed out of use. In its place, the cauterizing styptic with holders came to be used. In the later part of the eighteenth century, these were usually silver, about ten centimeters long, and about the thickness of a pencil with a screw cap. The use of the iron cautery had not entirely died out, however because the Maw catalog of 1868 displays several.³⁴

During the later middle ages, a military surgeon under Henry II, Francis II, Charles IX, and Henry III of France, by the name of Ambroise Paré (1509 - 1590), made many breakthroughs in wound closure. Stopping bleeding in the early middle ages was attempted by cauterizing, bandaging, or with boiling oil or pitch. Pare used ligatures, such as the one shown in Figure 1-3³⁵, to stop bleeding, and from this the idea of the tourniquet began to take shape. In 1674 a field garotte was used by Morell to stop the hemorrhage of a soldier. This was a simple cord with a wooden rod pushed beneath it and twisted to tighten it. In 1678, the garotte was successfully used by a naval surgeon in amputation, but this time,

³¹Majno 417.

³²Elisabeth Bennion. *Antique Medical Instruments* (Los Angeles, California: University of California Press, 1979) 183-184.

³³Bennion 184.

³⁴Bennion 184-188.

³⁵Bennion 180.



Figure 1-2: *The use of the cautery*; woodcut from *Albucasis*. From *Chirurgicorm Omnium*, 1532 in the Wellcome Museum Library.

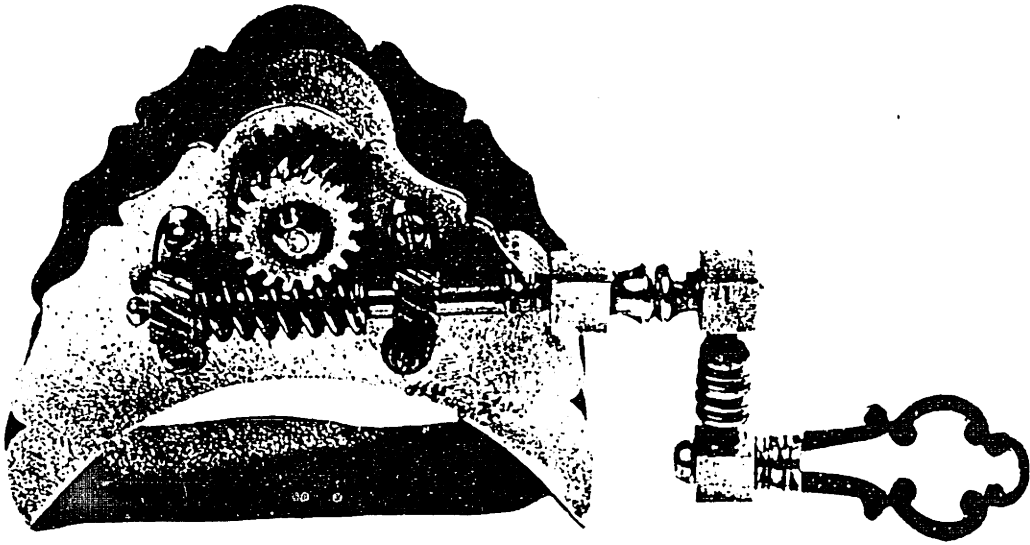


Figure 1-3: A Paré-Style Ligature, c. 1640. 10 cm. From Germanisches Nationalmuseum, Nuremberg.

a hard lined pad was placed over the vessel concerned. A device was then developed that used a rack through which the strap was passed with a handle to turn and tighten it.³⁶

In 1718, Jean-Louis Petit (1674 - 1760) invented a screw compressor which limited pressure to the artery, and he gave his instrument the name of tourniquet. The advantages of his instrument was that it could be held without assistance and the pressure relaxed or released at will. Rudimentary tourniquets on board ships were described in 1782 as being of stiff leather with a linen compress and a wooden cylinder to twist the tape for tightening. Many lives were saved by it when over a hundred men were waiting for the services of a surgeon at one time. Early in the nineteenth century, a tourniquet with a cog and wheel mechanism was tried. Original tourniquets were made of wood but later brass was used with a strong linen strap, and the compressor was covered in fine kid (Figure 1-4³⁷).³⁸

Ambroise Paré also was the first to develop a type of hemostatic clamp to arrest hemorrhage, which he called the Bec de Corbin ou de Perroquet. This instrument was to be used instead of the pitch or boiling oil previously applied after an operation. The clamp looked like a crows bill and had long serated jaws. It was held closed by various methods including sliding clamps, a rack or spring mechanism.³⁹

³⁶Bennion 179.

³⁷Bennion 180.

³⁸Bennion 179.

³⁹Bennion 66.

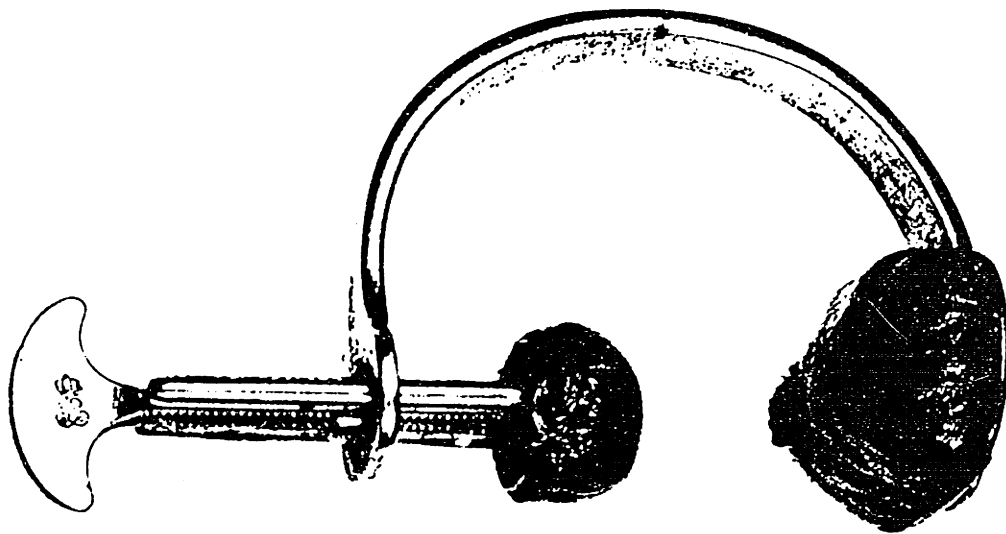


Figure 1-4: Garot Tourniquets, c. 1800. From Musée d'Histoire de la Médecine, Paris; Cliché Assistance Publique

Rhazes of Arabia used kitgut to suture abdominal wounds in 900 A.D.⁴⁰ Suturing instruments became somewhat perfected as the Medieval period progressed. Suturing the outer layers of the skin were carried out with ordinary sewing needles until the late eighteenth century when the needles became curved and specialized.⁴¹

Most of the common techniques of wound closure today are outgrowths of the ancient methods. Even many of the methods that have fallen out of use or deemed to be primitive or ineffective are still used by primitive cultures. For example, in New Guinea in 1961, Dani girls' fingers were chopped off with stone as a sacrifice. Their wounds were dressed in something similar to the plasters of ancient Mesopotamia. Their fingers were dressed in ashes and clay and then wrapped in leaves.⁴² Also, in Uganda in 1979, wound closure was still being performed using iron spikes wound around with a thread, similar to the fibulae of Rome.⁴³

We will examine the common and not so common modern techniques of wound closure in the following chapters. But first we must understand the mechanism of wound healing to fully comprehend the mechanisms by which the various wound closure methods function.

⁴⁰ *Wound Closure Manual: Use and Handling of Sutures, Needles, and Mechanical Wound Closure Devices* (New Jersey: Ethicon Inc., 1985) 9.

⁴¹ Bennion 70.

⁴² Majno 23.

⁴³ Majno 15.

Chapter 2

Wound Healing

One of the most important attributes of the human body is the capacity for self-repair. With few exceptions, cellular and biochemical mechanisms heal wounds quickly and efficiently. Supplemental drugs, vitamins, and dressings are seldom required. Yet proper wound management can be beneficial by discouraging unwanted events while promoting repair.¹

Basically in the process of wound healing, severed tissues must be held together until the healing process has reestablished sufficient strength to withstand stress without mechanical support. Tissues may be approximated with sutures, staples, clips, or adhesive skin closure strips. The choice of wound closure materials and techniques are prime factors in restoration of continuity and tensile strength to injured tissues during the healing process.²

There are three types of stresses that a tissue must withstand. The tissue must have tensile strength. Tensile strength is the greatest longitudinal stress that the tissue can withstand per unit area without tearing. Tensile stresses are caused by two forces of equal magnitude applied in opposite directions to the tissue. The second force that a tissue must be able to withstand is shear stress. The breaking strength of a tissue is the amount of shear stress that the tissue can withstand per unit width. Finally the burst strength of a tissue is the amount of pressure or compressive force that a tissue can withstand before rupture. An injury will occur when the tensile or compressive forces exceed the yield stress

¹John M Finley. *Practical Wound Management* (Chicago, Illinois: Year Book Medical Publishers, Inc., 1981) 3.

²*Wound Closure Manual: Use and Handling of Sutures, Needles, and Mechanical Wound Closure Devices* (New Jersey: Ethicon Inc, 1985) 3.

of the tissue.³

Different tissues vary in strength and speed of healing. The skin and fascia are the strongest tissues but regain their tensile strength slowly during wound healing. On the other hand, the stomach and small intestine are weaker tissues but they heal rapidly. In fact, variations in strength can occur within the same organ. Tissues can vary in strength from patient to patient depending on factors such as the age of the patient, the size of the patient, and variations in thickness due to differences in water and cellular content.⁴

2.1 Infection of Wounds

There are four major classifications of types of wounds, and the method and process of healing and intervention depends on which type of wound we are dealing with. The classification system depends primarily on the tendency to develop infection. The development of infection is the function of the interaction of several forces: the nature and degree of local contamination, local tissue features, and the therapeutic measures. Contamination refers to the viable and non-viable foreign bodies within the wound which have failed at this point, to elicit inflammation. Infection refers to a wound that shows the classic signs of inflammation.⁵

Bacterial contamination is the prerequisite for the development of infection. The relationship between bacteria and the development of infection is quantitative. A critical number of bacteria seems to be necessary to incite infection in soft tissue wounds. The infective dose is 10^5 aerobic organisms per gram of tissue. The species of microorganism is not important, with the exception of β -hemolytic *Streptococcus*. When the bacterial counts are below this level, the wounds will heal consistently without infection.⁶

The surgeon must focus attention on anatomic regions of the body containing concentrations of organisms sufficient to elicit soft tissue infection. These areas include the gastrointestinal, respiratory, and genitourinary tracts and the oropharyngeal cavity. Strict adherence to aseptic technique is mandatory to minimize the spread of endogenous contaminants.⁷

³Richard F. Edlich, John G. Thacker, George T. Rodeheaver, and Milton T. Edgerton *A Manual for Wound Closure* (Minnesota: Minnesota Mining and Manufacturing Co., 1980) 4-7.

⁴*Wound Closure Manual* 3.

⁵Edlich 18.

⁶Finley 8.

⁷Edlich 19.

Clean Wounds are nontraumatic, uninfected, undrained, and primarily closed operative wounds that do not enter the respiratory, gastrointestinal, or genitourinary tracts, or the oropharyngeal cavity. No break in aseptic technique occurs during the operating procedure. If the clean wound is drained, it is called a refined clean wound. Clean wounds have an infection rate of 3.3 percent, while refined clean wounds have an infection rate of 7.4 percent.⁸

Clean-Contaminated Wounds are operative wounds without unusual contamination. The wound may enter the oropharyngeal cavity, as well as the respiratory or gastrointestinal tracts without any serious spillage. The genitourinary and biliary tracts may be entered in the absence of infected urine or bile. These types of wounds also encompass clean wounds contaminated by a minor break in aseptic technique. The infection rate for these type of wounds is 10.8 percent, but may be able to be reduced to less than 5 percent by employing immediate antibiotic treatment.⁹

Contaminated Wounds are soft tissue lacerations, open fractures, penetrating wounds, and other fresh traumatic injuries. Gross spillage from the gastrointestinal tract can occur or the genitourinary or biliary tracts may be entered in the presence of infected urine or bile. These also include operations with a major break in aseptic technique such as the open heart massage. The infection rate in these wounds is 28.6 percent.¹⁰

Finally, Dirty and Infected Wounds are heavily contaminated or clinically infected prior to the operation. These include old traumatic wounds with retained devitalized tissue or foreign bodies or those involving abscesses or perforated viscera.¹¹ The infection rates of five classes of wounds are given in Figure 2-1¹².

2.2 The Biology of Repair

Ideal healing is by regeneration, a process by which the injured part is replaced by the same tissue that was destroyed. Several lower species heal by regeneration, but in humans, only the epidermis, the outermost layer of the skin, and the mucosa, the innermost layer of the intestine, can regenerate. Other tissues such as muscle, fat, blood vessels, fascia, etc., heal

⁸Edlich 20.

⁹Edlich 21.

¹⁰Edlich 21.

¹¹Edlich 21.

¹²Edlich 20.

REPORT OF AN AD HOC COMMITTEE OF THE COMMITTEE
ON TRAUMA - NATIONAL ACADEMY OF SCIENCE -
NATIONAL RESEARCH COUNCIL (1964)

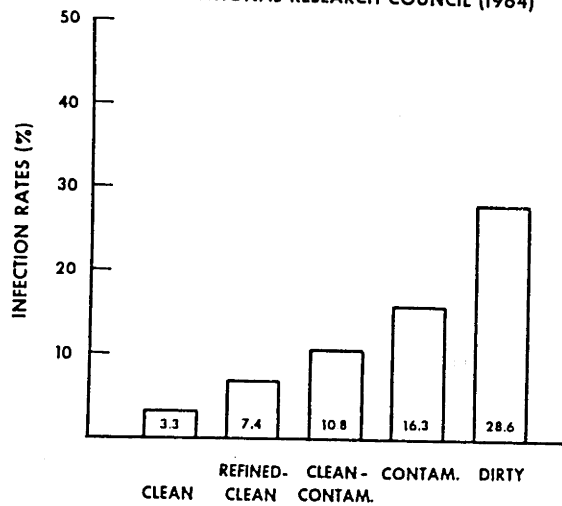


Figure 2-1: The Infection Rates of Five Classes of Wounds.

by laying down a white protein called collagen, which is the chief constituent of connective tissue.¹³

Depending on the type of wound and the particular situation, wounds heal by one of three intentions.

2.2.1 First Intention

First intention healing applies to closed wounds, and healing follows the initial closure of an incised, aseptic, accurately approximated wound with minimal edema and no serious discharge or local infection. Wounds healed by first intention heal in minimum time with no separation of wound edges and minimal scar formation. Clean wounds heal by first intention, as well as most refined-clean and clean-contaminated wounds.¹⁴

In basic clinical terms, wound repair by first intention involves epithelial cell migration over the skin defect (epithelialization), accumulation of the required substrates (inflammation), scar tissue formation (collagen synthesis), and late collagen remodelling (scar maturation).¹⁵

Epithelialization begins about twelve hours after the wound edges have been approxi-

¹³ *Wound Closure Manual* 3.

¹⁴ *Wound Closure Manual* 6.

¹⁵ Finley 3.

mated. The migrating epithelium completely bridges most wounds within 48 hours. This process requires an uninfected environment and is slowed by dry conditions.¹⁶

Immediately after the injury has occurred, defense mechanisms are set into action. For the first few days, the inflammatory defensive response produces an outpouring of tissue fluids, accumulation of cells and fibroblasts, amines, enzymes, fibrin, antibodies and plasma proteins, all the materials needed for healing. There is increased blood supply to the wound and leukocytes and other cells produce proteolytic enzymes to dissolve and remove damaged tissue debris and also ingest microorganisms. The early phagocytes are neutrophils, and are followed by the arrival of monocytes from bone marrow which become macrophages that digest the remaining debris. Swelling therefore occurs and is most pronounced on the second or third day. At the surface, fibrin and other proteins dry producing a scab that seals the wound and prevents further fluid loss and microbial invasion.¹⁷

After the debridement process is well along, and the inflammatory process has brought all the materials needed for collagen deposition into the healing wound, fibroblasts begin to form collagen fibers in the wound. Collagen already present adjacent to the healing wound is initially broken down by enzymes called collagenases. Because of this, around ten to fourteen days post wounding, the wound is at its weakest point. This is of great significance to colonic wounds. Collagen fiber formation influences tensile strength and pliability of the healing wound. In time, enough collagen is laid down across the defect, so that the wound will withstand normal forces put on it. The time element varies with the type of tissue, stresses or tensions upon it, and other factors influencing wound healing. Collagen first becomes apparent after four to six days and continues to increase until six weeks after the injury. Besides collagen synthesis, other damaged parts of connective tissue are replaced, lymphatics rechannelize, and capillaries develop to provide adequate blood supply.¹⁸

After six weeks, the process of early healing is considered complete and most wounds have achieved at least 50 percent of the strength of normal skin. At this time actual collagen content is highest, but as the next year progresses, the scar will mature (Figure 2-2¹⁹). This encompasses molecular reorientation of the collagen and its chemical cross-linking, which will strengthen the tissue further. Hypervascularity also decreases and the scars fade to a

¹⁶Finley 4.

¹⁷Wound Closure Manual 6.

¹⁸Wound Closure Manual 6.

¹⁹Finley 3.

Wound Healing

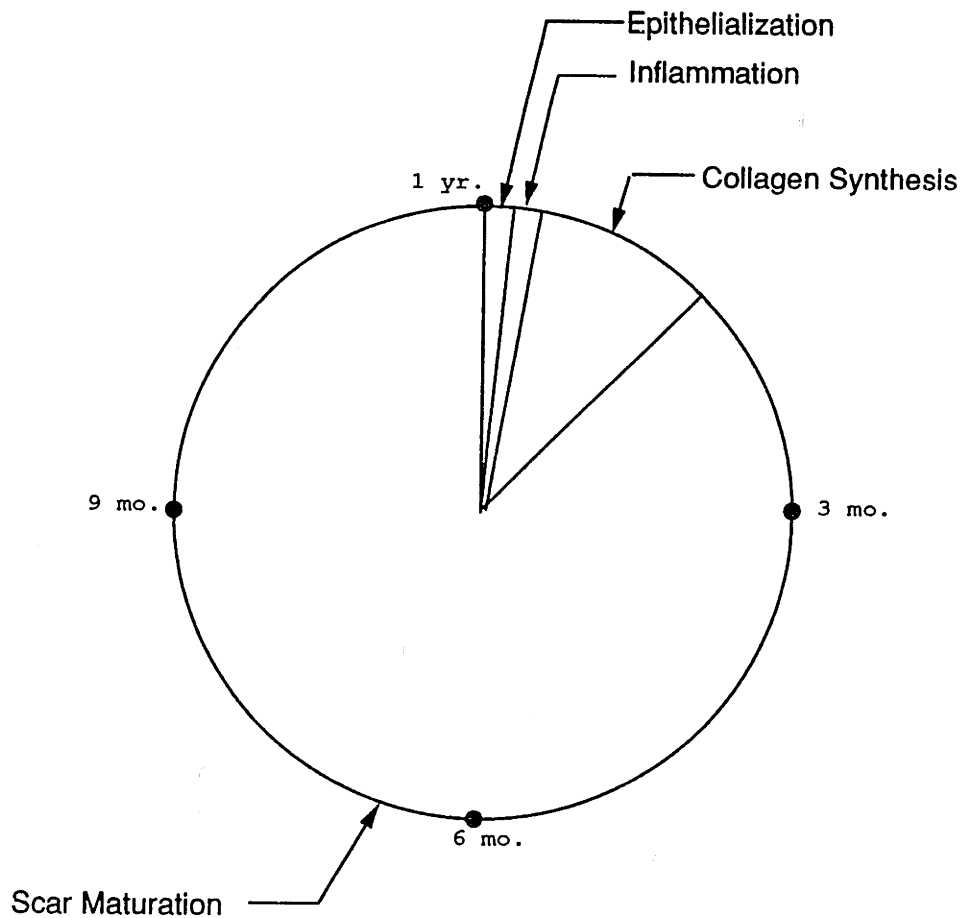


Figure 2-2: First Intention Wound Healing Time Scale

more normal skin color. The scars will also contract and flatten out.²⁰

2.2.2 Second Intention

Healing by second intention is the common pathway for open wounds (Figure 2-3²¹). In the presence of infection, excess trauma, loss of tissue, or imprecise tissue approximation, the wound may be left open and allowed to heal from the bottom toward the outer surface. The open wound depends on active contraction to achieve final closure rather than primary

²⁰ *Wound Closure Manual* 6.

²¹ Finley 4.

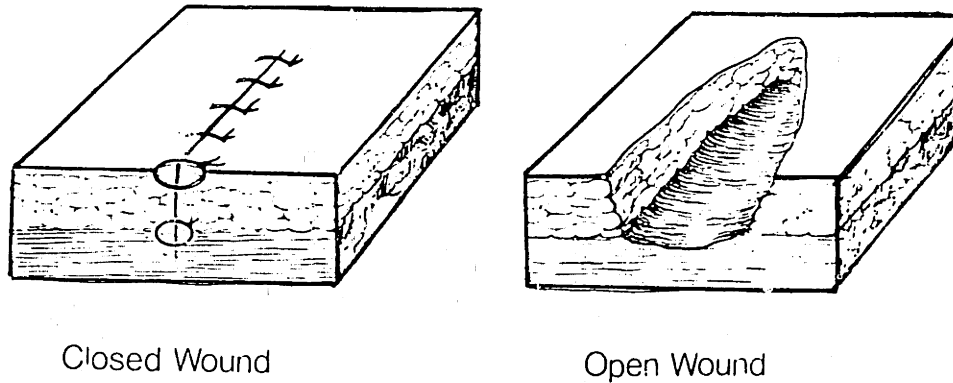


Figure 2-3: Closed vs. Open Wounds

union.²²

After a wound has been open for about five days, a velvet-like red layer of granulation tissue appears, consisting of myofibroblasts, cells which possess collagen-forming characteristics as well as contractile muscle cell characteristics. The myofibroblasts are the mechanism by which granulation tissue can actively pull wound edges centrally, shrinking the size of the defect to a size that can be epithelialized successfully.²³

The healing process is delayed in second intention and scar formation is excessive. A weak union may also be produced.²⁴

2.2.3 Third Intention

Healing by third intention also occurs with initially open wounds and is usually called delayed primary closure. This method is usually reserved for contaminated and dirty and infected wounds. The fundamental basis for delayed closure are the principles and practices of military surgeons. Immediate closure of dirty or contaminated wounds frequently (more than 20 percent) results in the development of purulent discharge, wound dehiscence, and eventually sepsis. Management of these wounds is best accomplished by leaving them open until delayed closure can be undertaken without risk of later infection. Wounds resulting from high velocity injuries, and wounds with great tissue loss also are healed by third

²² *Wound Closure Manual* 7.

²³ Finley 5.

²⁴ *Wound Closure Manual* 7.

OPTIMAL TIME FOR DELAYED PRIMARY CLOSURE

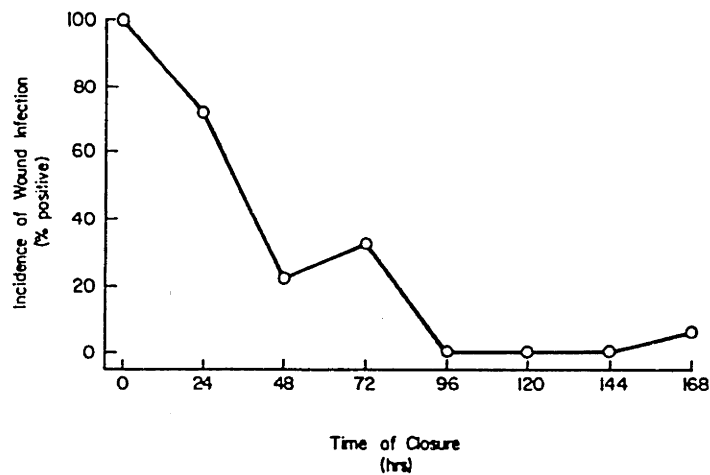


Figure 2-4: Optimal Time For Delayed Closure

intention.²⁵

The healing open wound gradually gains enough resistance to infection to allow an uncomplicated closure. The reparative process that endows the wound with greater resistance to infection is the development of capillary buds and young, fibrous granulation tissue. The optimal time for delayed closure is four to six days post-injury (Figure 2-4)²⁶. Healing by delayed primary closure produces a deeper, wider scar.²⁷

2.3 Factors Influencing Wound Healing

There are many factors that affect the speed with which wounds heal and the extent to which wounds regain their initial strength. These factors can range from overall conditions of the patient to conditions at the site of injury. Therefore two basic divisions can be made within the factors that affect wound healing, systemic factors and local factors.

²⁵ *Wound Closure Manual* 7.

²⁶ Edlich 26.

²⁷ *Wound Closure Manual* 7.

2.3.1 Systemic Factors

Two of the most important factors affecting wound healing are the age and weight of the patient. The larger the age and weight, the slower the healing process. This is because skin and muscle lose tone and elasticity as natural characteristics of the aging process. Excess fat sometimes inhibits the securing of good closure. Fat is the most vulnerable of all tissues to trauma and infection because of its poor blood supply.²⁸

Malnutrition also delays wound healing. Many of the components necessary to healing are lacking in undernourished people. Carbohydrates contribute to the healing process. Vitamin B is necessary for carbohydrate metabolism. Proteins also support cellular activities essential to wound healing. Plasma proteins provide the essential amino acids for collagen synthesis into scar formation. Other vitamins and minerals necessary are vitamin A and zinc for collagen synthesis. Therefore, vitamin deficiency and zinc deficiency also affect wound healing.²⁹

Dehydration also delays wound healing by changing the fluid and electrolyte balance. This impairs kidney function, cellular metabolism, oxygen concentration in the circulatory system and hormonal function. Without these aspects of the body functioning properly, the healing process is slowed down.³⁰

Drugs that the patient may have been taking may adversely affect the healing process. Specific examples of such drugs are anti-inflammatory drugs, cytotoxic drugs, and prolonged high doses of steroids preoperatively. For example, cortisone and progesterone inhibit fibroplasia and formation of collagen.³¹

The general condition of the patient affects wound healing. Diseases such as diabetes mellitus, jaundice, anemia, leukopenia, uremia and other malignant diseases slow down wound healing. Systemic infection also inhibits swift wound healing as does the general immune responses and the temperature of the body. There may be functional abnormalities in the immune responses of the body due to allergic reactions. In fact any trauma to the body will affect the wound healing process.³²

²⁸ *Wound Closure Manual* 4.

²⁹ Diane Krasner. *Chronic Wound Care* (King of Prussia, Pennsylvania: Health Management Publications, Inc., 1990) 21.

³⁰ *Wound Closure Manual* 4.

³¹ Krasner 21.

³² Krasner 21.

2.3.2 Local Factors

Healing is fastest in areas with the greatest blood supply. Healing is impaired by any deficiency in blood and therefore oxygen supply. Poor blood supply also slows down the rate at which components necessary for the healing process reach the wound. For example, several plasma proteins are necessary for collagen synthesis. These include albumin which plays a part in collagen cross-linking and ceruloplasmin which is essential for collagen formation and maturation. Blood supply in tissues decreases following large doses of radiation.³³

Other factors that may affect the healing process include the amount of devitalized or dead tissue within the wound, the extent of denervation, the presence and types of foreign bodies in the wound, the extent of local infection the nature and location of the wound, the type of tissue, and the amount of protection.³⁴

Four extremely important local factors affecting wound healing are surgical principles which often involve suture material and technique, postoperative infection, wound disruption, and mechanical stress and tension on the wound. I will go more into depth about these factors because they can be controlled.

Surgical Principles

The maintenance of sterile and aseptic techniques to prevent infection are of utmost importance to successful healing. Microorganisms can be carried by the personnel or the patient himself.³⁵

The location, length and depth of all surgical incisions should be properly planned so that they are just large enough to afford sufficient operating space. The direction of the incision is also important because wounds heal side-to-side, not end-to-end. Incisions should be clean, and of evenly applied pressure, and in one direction. Tissues should be handled gently and as little as possible to minimize trauma to a minimum.³⁶

The physician must complete hemostasis before the wound is closed to prevent hematoma formation. A hematoma or seroma in the incision prevents direct apposition which is essential to the union of wound surfaces. They can also act as culture medium for microbial

³³ *Wound Closure Manual* 4.

³⁴ Krasner 21.

³⁵ *Wound Closure Manual* 4.

³⁶ *Wound Closure Manual* 5.

growth which could lead to wound infection.³⁷

Care must also be taken to preserve the blood supply which is essential for the removal of foreign bodies. Periodic irrigation with warm physiologic saline solution or covering exposed surfaces with saline-moistened sponges or laparotomy tapes helps avoid drying of tissues. Finally adequate immobilization of the approximated wound is mandatory for efficient healing and minimal scar formation.³⁸

Postoperative Infection

Despite precautions, postoperative infection may develop. The invasive organism should first be identified by obtaining a specimen of the drainage or tissue culture. Adequate incision and drainage is of primary importance. Debridement of necrotic tissue should be done as needed. Without these steps, no course of antibiotic therapy will succeed. Appropriate antibiotic treatment for the particular organism can then be initiated. Postoperative infections can be classified by the source of the infection, the associated anatomical or pathophysiological changes, or the microbial etiology.³⁹

Wound Disruption

Dehiscence is the partial or total separation of layers of wound closure. In this case, the wound does not have to reclosed. Reclosure depends on the disruption event. Evisceration, on the other hand, is an emergency situation. It involves the protrusion of the bowel through the separated edges of an abdominal wound closure. The bowel must be replaced and the wound must be reclosed rapidly.⁴⁰

The location and direction of the incision are important factors for wound disruption. Dehiscence is most frequent in vertical incisions in the upper part of the abdomen because of the relative tenseness of the muscles and fascia in this area. Therefore the highest incidence of dehiscence occurs following gastric operations, biliary tract operations and intraabdominal cancer operations. Cancer also leads to debility and hypoproteinemia which could lead to impaired wound healing and subsequent wound disruption. Distention, vomiting and coughing lead to increased intraabdominal pressure which leads to increases tension in the

³⁷ *Wound Closure Manual* 5.

³⁸ *Wound Closure Manual* 5.

³⁹ *Wound Closure Manual* 8.

⁴⁰ *Wound Closure Manual* 8.

wound and this is the major cause of evisceration and dehiscence prior to day five. Wound disruption is most common in older age groups and more often in males than females, between day five and day twelve.⁴¹

Stress and Tension on the Wound

A cellular response occurs whenever foreign materials, including sutures and staples are implanted in tissues. Usually this reaction is slight to moderate depending on the tissue type and implanted material. The reaction is greater if there is infection or trauma. After the closing of an incision, edema of the skin and subcutaneous tissue always follows. Therefore tight skin sutures or embedded staples can lead to patient discomfort and scarring secondary to ischemic necrosis. Ischemia is a decreased blood supply to the tissues. Tissues must be closed with enough tension to bring wound edges together and eliminate dead space, but loose enough to prevent tissue strangulation and necrosis by ischemia. The purpose of eliminating dead space is to prevent serum or blood collecting there and promoting infection. Insertion of a drain or pressure dressing application may eliminate dead space in a wound postoperatively. The fascia may be placed under high tension during coughing, vomiting, or defecating, and wounds in high tensions, such as abdominal wounds need longer support.⁴²

2.4 Growth Factors

Successful wound repair is essential for survival. The process of wound repair involves a complex interaction between cells, biochemical mediators, extracellular matrix molecules, and the cellular microenvironment. Wound repair is thought to be heavily influenced by locally acting growth factors. These biomolecules are usually small peptides and they influence cell proliferation, movement, and biosynthetic activity. They can be transported in the blood, they can be produced by one cell type to act on another in the local area (paracrine factors), or they can be produced by a cell acting on itself (autocrine factors). Most of the cellular activities in wounds appear to be regulated at least in part by presently known growth factors.⁴³

Locally acting growth factors are grouped into three categories: factors that signal cells

⁴¹ *Wound Closure Manual* 8.

⁴² *Wound Closure Manual* 4.

⁴³ Krasner 433.

to proliferate, factors that stimulate migration, and factors that alter the phenotypic status of the cell.⁴⁴

Mitogens are factors that regulate cellular division. These are divided into two categories, competence and progression factors. In order for cells to divide, they must be stimulated to go from resting state, G₀, to a state of readiness to replicate DNA and divide, G₁. Competence factors stimulate cells to undergo this transformation. Once cells enter G₁, the presence of progression factors is required for progression through the cell cycle. Competence factors include platelet-derived growth factor (PDGF) and epidermal growth factor (EGF). Progression factors include insulin-like growth factor (ILG-1) and the other somatomedins. These progression factors circulate in the plasma and are available to cells stimulated to enter G₁, and they are also secreted by fibroblasts in wounds and therefore act as autocrine factors.⁴⁵

Chemoattractants induce cell migration. These are also divided into two categories, chemotactic factors and chemokinetic factors. Chemotactic factors work through cell surface receptors that cause the target cell to move in a given direction when reaching one side of a cell in higher concentrations than the other. Chemokinetic factors increase the rate of migration. Chemotactic factors include C5a, which is a chemotactic for neutrophils and PDGF, which is chemotactic for fibroblasts. Albumin is a chemokinetic for neutrophils.⁴⁶

Finally, transforming growth factors affect the phenotypic state of the cell. Transforming growth factor beta (TGF β) has several different activities. In certain concentrations, it inhibits fibroblast division and stimulates increased production of matrix molecules such as collagen and glycosaminoglycans. In certain cells it induces the production of PDGF. Transforming Growth Factor (TGF α) shares homology to EGF, binds to the same receptor and evokes similar responses.⁴⁷

2.4.1 Summary of Growth Factors

Platelet-Derived Growth Factor Platelet-derived growth factor is a 30 kilodalton glycoprotein, consisting of two disulfide-linked subunits. It is found in platelets, monocytes, smooth muscle cells, endothelial cells, and various transformed cells. It binds to high affinity

⁴⁴Krasner 433.

⁴⁵Krasner, 433.

⁴⁶Krasner 434.

⁴⁷Krasner 434.

receptor sites, is active in the picomolar range, and is a powerful mitogen for mesenchymally derived connective tissue cells. It is a chemotactic factor and a competence factor.⁴⁸

Epidermal Growth Factor Epidermal growth factor is a six kilodalton protein of a single chain of 53 amino acids. It binds to high affinity receptor sites, and can be found in platelets, salivary glands, duodenal glands, and urine. It is a competence factor for epithelial and mesenchymal cells.⁴⁹

Angiogenesis Factors Angiogenesis is the process of new capillary formation. Angiogenesis involves four activities: capillary endothelial cell migration, proliferation, protease production, and differentiation into tubes. An angiogenic factor is present in platelets and macrophages. This factor has been isolated but not purified. It weighs between two and 14 kilodaltons, is a protein, and is stable in acid and heat. It causes capillary cell migration and neovascularization.⁵⁰

Fibroblast growth factors (FGF) are the mitogens which produce endothelial cell proliferation after migration. FGF has acidic and basic forms which differ from 16 kilodaltons to 18 kilodaltons. It binds to high affinity receptors and is found bound to basement membranes. Both forms are acid and heat labile and are single polypeptide chains. FGF is a strong mitogen for mesodermal and endothelial cells. It is secreted by the endothelial cell and is secreted into basement membranes.⁵¹

A very low molecular weight factor has been isolated which induces enzyme production in capillary endothelial cells and is probably responsible for the increase in proteolytic enzyme production. The proteolytic enzyme is produced to aid the capillary endothelial cell to break through the basement membrane to migrate. FGF also stimulates the production of proteolytic enzymes by capillary endothelial cells.⁵²

Transforming Growth Factor β TGF β is a 25 kilodalton protein comprised of two chains. It is found in platelets, macrophages, and lymphocytes and is secreted as a high molecular weight precursor which is cleaved at low pH. It is stable in acid and heat and

⁴⁸Krasner 434.

⁴⁹Krasner 434.

⁵⁰Krasner 434.

⁵¹Krasner 434.

⁵²Krasner 435.

binds to high affinity receptors on the target cell. It inhibits cellular proliferation, is a chemoattractant, stimulates macrophages, and produces increased collagen and fibronectin production from fibroblasts and keratinocytes.⁵³

Angiogenesis Inhibitors Inhibition of neovascularization is as important to wound repair as stimulation. When growing granulation tissue is covered with new epithelium, an inhibitor of angiogenesis is probably produced to suppress granulation tissue growth. Known inhibitors include, cartilage-derived growth factors, retinal pigment epithelium inhibitor, and the combination of heparin-like molecules and certain steroids.⁵⁴

2.4.2 Repair With Growth Factors

Traumatic tissue injury exposes plasma to connective tissue proteins, activating factor XII. Activated factor XII activates clotting, kinin, complement and plasmin cascades. The clotting cascade produces thrombin which stimulates platelets to release alpha granules, and fibrin which produces the first matrix filling the wound space. Alpha granules contain most of the growth factors. The kinin cascade produces bradykinin which causes microvascular vasodilation at the wound edge to increase circulation in the capillaries. Complement activation produces C5a which attracts neutrophils and monocytes to the wound space. These cells control bacterial contamination of the wound and clear cellular debris. Monocytes mature into macrophages which produce growth factors. The plasmin cascade produces plasmin which degrades the fibrin, starts the remodeling process, and releases fibrin degradation products which are chemoattractants for macrophages and activate them as well.⁵⁵

When the platelets release the alpha granules in the wound, the connective tissue formation process starts. PDGF, PDAF, TGF β , and EGF are released. Macrophages continually release PDGF, macrophage angiogenesis factor and TGF β throughout wound repair. The combination of the latter three growth factors produce granulation tissue which fills the wound space. PDGF also stimulates wound contraction. EGF and PDGF stimulate epidermal cells to migrate and divide to cover the granulation tissue. As the wound heals, the size of the wound space decreases. The growing tissue completely fills the wound and signals the wound to stop repair since oxygen tension is high enough to shut off macrophage

⁵³Krasner 435.

⁵⁴Krasner 435.

⁵⁵Krasner 436.

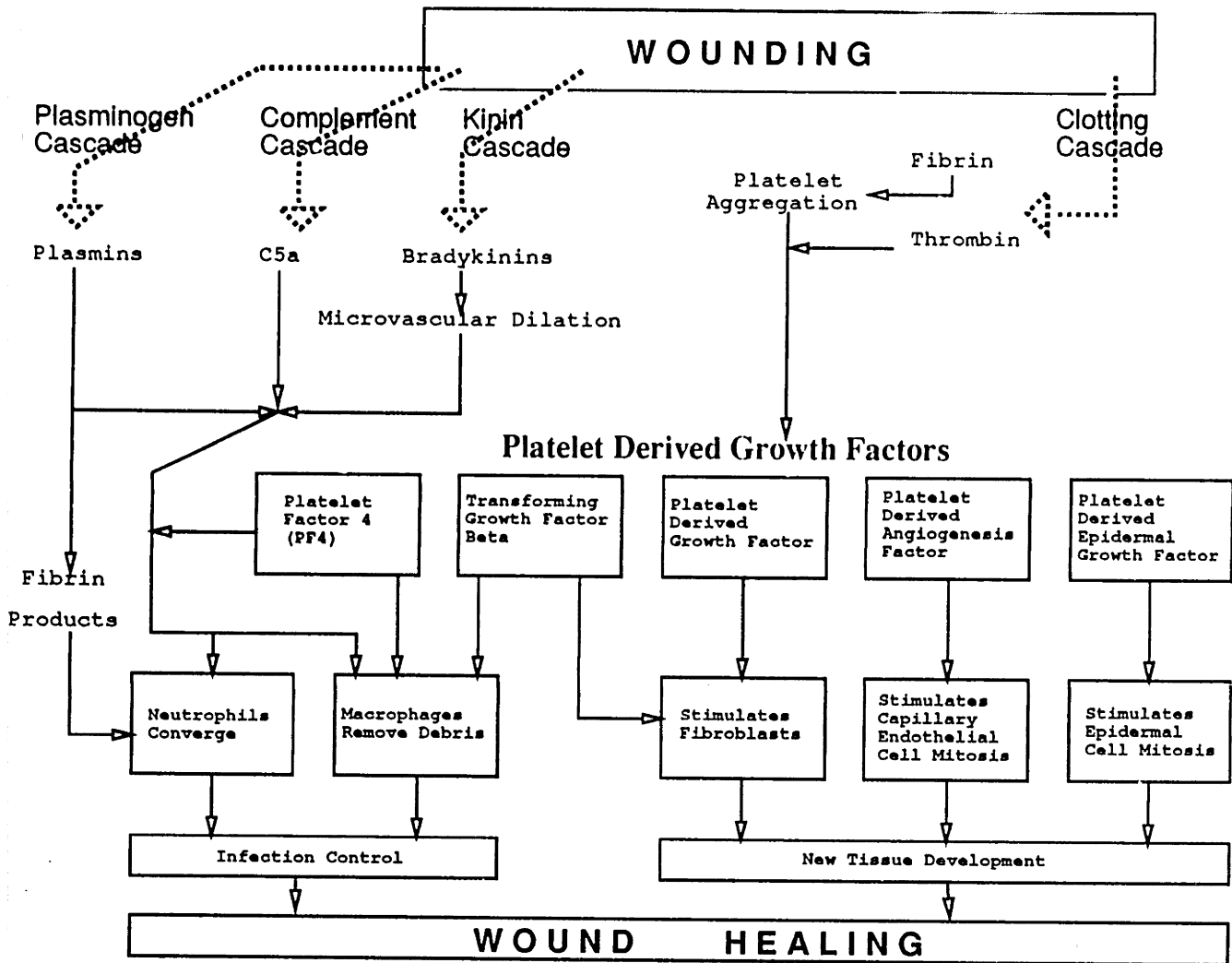


Figure 2-5: The Wound Healing Process

angiogenesis factor production. Also plasma leakage is stopped which shuts off an important source of growth factors. Also the process of epithelialization and the production of angiogenesis inhibitors causes active inhibition of angiogenesis factor activity.⁵⁶ The entire process of repair with growth factors is depicted in Figure 2-5⁵⁷.

⁵⁶Krasner 436-437.

⁵⁷Krasner 432.

Chapter 3

Dressings

Simple wound dressings were one of the earliest forms of medical treatment. The dressing of wounds has been of great interest to those who provide medical care. Traditional interest in wound care has grown with recent advances in the knowledge of hemostasis, inflammation, and reepithelialization, and with the development of many new types of wound dressings.

The four stages of wound healing produce some obvious implications for dressings. In the epithelialization stage, a dressing can be used to keep the wound clean until the intact skin, usually after two days, can resume this function. During the inflammatory stage, swelling is produced. A dressing that is applied closely immediately after an operation may be strangulating a couple of days later. A slightly tight dressing on the other hand can decrease edema and speed recovery under certain conditions.¹

A dressing can be used to support the tissues until about six weeks after injury, when much of the wound's strength has returned due to collagen deposition. If the skin is subject to tension during the collagen deposition stage, tape can help to minimize scar widening.²

During the period of scar maturation, proper splinting can counteract wound contraction, and constant, prolonged external pressure can influence collagen remodelling and can prevent excessive collagen deposition which causes scar hypertrophy.³

¹John M. Finley. *Practical Wound Management* (Chicago: Year Book Medical Publishers, Inc., 1981) 7.

²Finley 7.

³Finley 7.

3.1 Functions of Wound Dressings

During wound healing, a properly designed and applied dressing can be extremely beneficial, promoting recovery and ensuring comfort. The following physiologic functions of wound dressings can be considered singly or in combination to design a dressing for specific needs.⁴

The primary function of a dressing is protection. A dressing can protect the wound from further trauma, environmental temperature changes, endogenous and exogenous bacteria, and body secretions. It also protects by assuring cleanliness.⁵

A second function of dressings is antisepsis. The dressing can contain chemical components that are either bacteriocidal or bacteriostatic. These compounds can change the relative concentrations of different kinds of bacteria in the wound. These agents should decrease the number of pathogenic bacteria. Some antiseptics and germicides are harmful to the cells and interfere with the repair process and should not be used routinely or at all once the infection has resolved.⁶

A third function of dressings is compression. Compression can minimize fluid accumulation in intercellular tissue spaces as well as decrease bleeding. A correct degree of compression decreases dead space, minimizing the accumulation of fluids that serve as a medium for infection. As bleeding and infection are decreased, so is potential hematoma formation, and therefore scar formation, wound dehiscence, and infection. Compression also brings the various layers of the dressing together to allow them to function cooperatively, and allow the dressing to function effectively. Compression also reduces tension on a wound, encouraging wound healing. A compression dressing immobilizes the area covered by the dressing and the more convex the surface of the dressing, the greater the pressure effect of the dressing on the tissue.⁷

Still another function of dressings is immobilization. Immobilization helps to prevent disruption of the fibrin and newly formed capillaries. Splints, adhesive tape, and plaster are all used to immobilize a wound until the wound has regained adequate strength from collagen synthesis. Immobilization also encourages rest which promotes natural healing of tissues.⁸

⁴Finley 13.

⁵Ross Rudolph and Joe M. Noc. *Chronic Problem Wounds* (Boston: Little, Brown, and Co., 1983) 37.

⁶Rudolph 37.

⁷Rudolph 37-38.

⁸Rudolph 38.

Dressings are also used for debridement purposes. Necrotic debris becomes entwined within mesh of dressings aided by capillary action. Rougher materials and wider meshes produce more efficient debridement action.⁹

Dressings control the immediate environment of the wound to create a conducive healing setting. Moistness prevents crusting and promotes epithelialization. Warmth localizes abscesses by the dilation of vessels, and acceleration of the local enzymatic processes, and dryness prevents maceration and bacterial proliferation. For deeper tissues, an environment resembling the body prevents loss of important factors from the wound.¹⁰

Absorption of blood, serum, pus and necrotic debris from the wound is also an important function of dressings. Hydrophilic surfaces on dressings draw water soluble material from the wound, minimizing maceration and infection. This type of dressing should be changed frequently.¹¹

Finally dressings can be used to minimize scar formation. For example skin taping prevents scar widening, and scar hypertrophy can be controlled by external pressure.

Of course, a dressing also provides comfort to the patient, is more aesthetic, and should not do any harm to the wound.

3.2 Types of Natural Dressings

No single wound dressing possesses all of the ideal characteristics. Wound treatments must be based on clinical findings that reflect the stages of wound healing. Dressings should be three-layered, consisting of the contact layer, the intermediate layer, and the outer wrap (Figure 3-1). A three-layer dressing allows capillary action to function with maximum effect so that the dressing can drain a wound by removing secretions and act as a barrier to protect the wound from contamination by exogenous fluid.¹²

3.2.1 The Contact Layer

The contact layer is next to the wound, and is the most important part of the dressing. A contact layer must meet several requirements. A contact layer must be sterile, must

⁹Rudolph 38.

¹⁰Rudolph 39.

¹¹Rudolph 39.

¹²Rudolph 40.

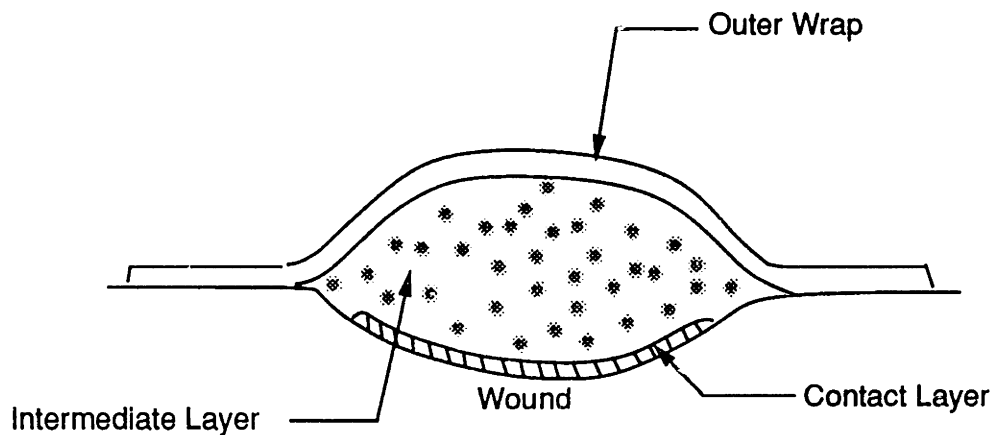


Figure 3-1: A Three-Layer Dressing

stay in close contact with the wound at all times to prevent maceration, and must conform to all body contours. For draining wounds, it must allow drainage to pass through to the intermediate layer without itself becoming wet, and on nondraining wounds, it should protect the wound from exogenous contamination sources. The material should be a fine enough mesh to prevent penetration by granulation tissue to prevent adherence. It should only adhere when debridement is the goal. Finally the contact layer should minimize pain, prevent unnecessary fluid loss, be nontoxic, and non-irritating. There are three types of contact dressings: absorbant, nonabsorbant, and occlusive.¹³

Absorbant Dressings

A material is absorbant if it provides a network of small openings that draw liquid into the dressing by capillary action until all of the openings are filled and absorption ceases.¹⁴

A common absorbant dressing is gauze dressing. Gauze dressing has many different uses as a dressing. A dry fine-meshed gauze is often used to achieve hemostasis in a dirty and infected wound. Wide mesh gauze, directly on the wound's surface is used in dirty and infected wounds to speed up debridement (Figure 3-2). The gauze is frequently changed. Debridement can also be achieved by keeping the gauze wet with Dakin's solution at half strength (dilute sodium hypochlorite). This dressing should be changed frequently. Dextranomer (Debrisan) is a mechanical agent to remove necrotic debris clinging to it, and

¹³Rudolph 41-42.

¹⁴Rudolph 41-42.

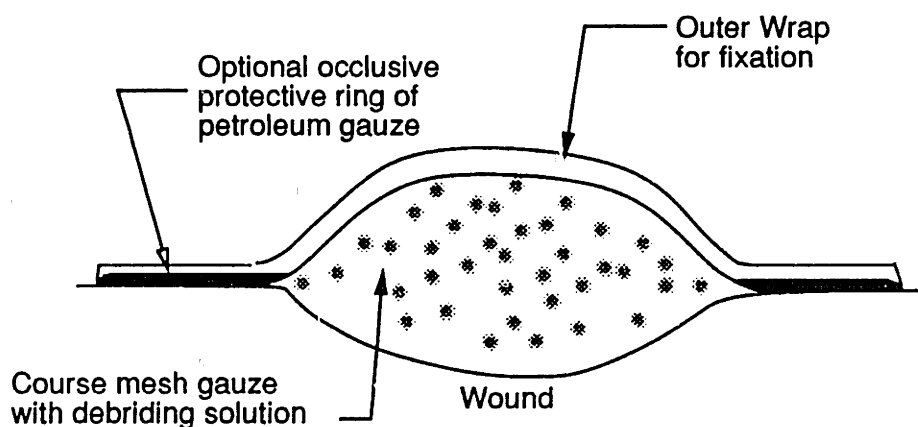


Figure 3-2: Dressings Used for Debridement

Travase is a chemical debriding agent.¹⁵

Gauze dressing is also used to carry an aniline dye such as Scarlet Red which accelerates the growth of epithelium, as long as the gauze does not bind to the wound. Gauze dressings often carry antibiotics often in the form of topical agents such as 0.1 percent gentamycin sulfate ointment, silver sulfadiazine, mafenide acetate, or silver nitrate. Antimicrobial agents such as Bacitracin and Neosporin which contain polymycin B, neomycin, and bacitracin are also used, as are iodophor ointments. Ointments also provide moist environments to prevent adherence of the dressing to the wound. Wound soaks are also used to deliver antibacterial agents such as 0.5 percent AgNO_3 and dilute Dakin's solution. The rapid changes of soak dressings prevent adherence of gauze into the wound.¹⁶

Dry absorbant gauze however is rarely used in a clean wound because it becomes quite adherent to the wound if the wound secretions dry by evaporation, trapping the dressing in the scab. Also, if it is too thick, it can become occlusive when saturated with wound dressings, and this would promote maceration and infection. Gauze dressings also shed particles and fibers into the wound sometimes, risking a foreign body reaction, and provide slow healing relative to more modern dressings. Petroleum jelly is sometimes used to prevent adherence, but this decreases absorbancy.¹⁷

¹⁵Finley 16.

¹⁶Diane Krasner. *Chronic Wound Care* (King of Prussia, Pennsylvania: Health Management Publications, Inc., 1990) 302-303.

¹⁷Rudolph 43.

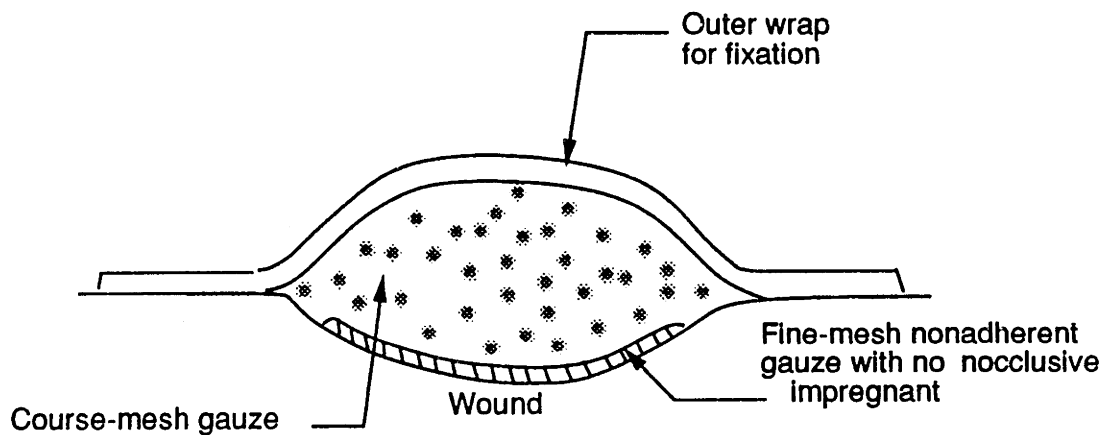


Figure 3-3: Nonabsorbant Dressings

Nonabsorbant Dressings

Often nonadhering contact dressings are made by impregnating absorbant materials like cotton or rayon (Figure 3-3). These dressings can be tailored to the needs of the wound by choosing the right impregnant. A hydrophilic impregnant can be used to drain wounds. A hydrophobic impregnant can be used to protect against exogenous fluid contamination or when partial occlusion is needed. Impregnants soften the dressing so that it clings to the surface of the wound, and at the same time the impregnant acts as lubrication so that the danger of the dressing sticking to the wound is minimized. Also, since the dressing fibers are saturated, the contact dressing does not absorb wound secretions.¹⁸

Hydrophilic contact dressings allow aqueous exudates and transudates to pass to the second layer by capillary action, where they are stored till the dressing is changed. The impregnated hydrophilic dressing is nonabsorbant, so it will not hold the secretions in contact with the wound. As long as the overlying absorbant layer does not become saturated, the contact layer will maintain a relatively dry wound, and this will minimize risks for maceration. Maceration can be prevented by ensuring that the second layer is changed before saturation or by starting with an intermediate layer that is thick enough to absorb all the anticipated drainage.¹⁹

Hydrophobic contact dressings are used when attempting to protect the wound from contamination by external fluids. The intermediate layer stores the fluid that may enter

¹⁸Rudolph 43.

¹⁹Rudolph 43.

from the outside. Some hydrophobic contact layers are semioclusive, and allow some secretions to escape. An example is Xeroform gauze. These dressings do not stick to the wound and should be used when heavy secretion is expected.²⁰

Occlusive Dressings

Occlusive dressings enhance epithelialization rate. Occlusive films maintain hydration and prevent loss of viable wound tissue by scab formation and dehydration. New epithelium can spread over the wound without having to go under a thick scab of dry tissue. Epithelial continuity is achieved quickly. Occlusive dressing are not used frequently however, because of concern over bacterial growth and tissue maceration. Occlusion of the skin's surface has been shown not only to prevent dehydration and raise surface temperature, but also to increase bacterial growth. This is because occlusive materials prevent drainage from secreting wounds, and fluid accumulate. Fluid accumulation, along with temperature elevation and maceration, may lead to infection.²¹

3.2.2 The Intermediate Layer

The intermediate or second layer should be a somewhat thick mass of soft absorbant material, overlaying the contact layer. It should remain in close contact with the contact layer everywhere. The material can be woven, unwoven, fine or coarse mesh. The thicker the layer, the greater the absorptive capacity to avoid frequent changes. It also acts as a cushion to avoid further trauma to the wound and as a splint to avoid movement at the wound site.²²

3.2.3 The Outer Wrap

The outer wrap, third layer, or binder, holds the first two layers in contact with each other and with the wound. It may also permit mobility of the injured part when required. It should be somewhat elastic and self adherent to compensate for any possible edema and to prevent slipping of the dressing when the injured part is mobile. Adhesive tape is sometimes used as a binder as long as it is not applied circumferentially. Stretch gauzes, Ace elastic

²⁰Rudolph 43-44.

²¹Rudolph 44.

²²Rudolph 44

bandage, and elasticised tape such as Elastoplast are also used. Montgomery straps can be untied and tied as dressings are changed, and therefore reduce trauma from frequent adhesive tape changes. Sometimes rolled gauze such as Kling is used to cover the bulky intermediate layer. This gauze is woven so that it conforms to the surface of the dressing, and if applied properly, offers compression that aids in eliminating dead space and minimizes edema just as well as elasticized bandaging. The extreme in immobilization is sometimes provided by plaster, especially for young children who destroy less durable coverings.²³²⁴

3.3 Synthetic Dressings

Synthetic dressings belong to one of four types of products: polymeric films, polymeric foams, particulate and fibrous polymers, and hydrogels and hydrocolloids.

Polymeric film dressings are used for short-term use to cover superficial wounds, partial-thickness burns, avulsions, autograft skin donor sites. They are used when the goal is to re-epithelialize an injury. They mimic the performance of skin, are transparent, and adhesive. They are elastomeric copolymers with an adhesive contact surface, are permeable to water vapor and are impermeable to water and bacteria.²⁵ These dressings provide a compromise between the positive effects of partial occlusion, increasing the rate of epithelialization and decreasing pain, and the negative effects, possible fluid accumulation, temperature elevation, maceration, and infection.²⁶

Adherent elastomeric polyurethane film wound dressings such as Bioclusive, OpSite, and Tegaderm, provide a moist condition that prevents harmful desiccation of wound cells. External oxygen may penetrate the film to maintain an aerobic environment and the trapped wound exudate fluid provides the nutrients and maintains relatively normal biochemistry for re-epithelialization. This type of environment has been shown to shorten wound healing times and can also relieve significant discomfort. Elevated levels of white blood cells are attracted to the wound surface and protect against microorganisms trapped under the film. The adhesive of OpSite is bacteriocidal and facilitates phagocytosis by neutrophils. The combination of bacteriocidal adhesive and polymorphonuclear leukocytes have been shown to result in

²³Rudolph 45.

²⁴Finley 18-19.

²⁵Krasner 33-34.

²⁶Rudolph 45.

less than 10 percent infection rates for OpSite dressing. There are disadvantages to these type of dressings however. They require a border of intact, uninjured skin for adhesion of the dressing. A significant amount of wound exudate accumulates and must be drained manually with a syringe or leakage might occur. There are also restrictions on location and areas that the dressing can be placed. These dressings are most useful in clean, non-draining partial-thickness wounds, and are not useful in chronic, draining, deep wounds.^{27,28}

A second type of synthetic wound dressing that is semi-occlusive, gas and water permeable, and used for the short-term, is derived from modified polyurethane. Examples of these polymeric foams include Epi-Lock, Coraderm, and Lyofoam. They insulate the wound surface and maintain a 37° C temperature, which speeds up epithelial cell growth by maintaining a high epithelial cell mitotic rate and maximizes phagocytosis of bacteria and wound debris. These foams may be used as a substitute for high absorbancy dressing pads and are placed over wounds with surgical tapes, surgical staples, elastic net, or fine-mesh gauze wraps. These are useful dressings for burns and partial-thickness wounds.²⁹

Particulate and fibrous polymeric products create a moist environment to liquefy eschar and necrotic debris, to reduce existing bacterial contamination, and act as a barrier to secondary infection. This is important in wounds requiring debridement before cell division can be initiated. Dextranomer beads can be inserted directly into the wound to absorb exudate and form a gel that continues to absorb exudate, dead cells, and bacteria. The gel is removed with saline prior to dehydration.³⁰

Another polysaccharide dressing material is made from calcium alginate and looks like a non-woven fibrous mat. The mat is placed directly on the wound, and absorbed exudate forms a gel. Alginic acid is a block copolymer of two monosaccharide units, D mannuronic acid and L guluronic acid. These acids are present in varying proportions. Commercially available products increase the cell growth of fibroblasts and include Kallostat and Sorbsan. The calcium stimulates cell division and enhances macrophage endocytosis.³¹

Both of these types of products are xerogels, which is the material that remains after most of the water from a hydrogel has been removed. In addition to granular and fibrous

²⁷Rudolph 15.

²⁸Krasner 304-305.

²⁹Krasner 305.

³⁰Krasner 35.

³¹Krasner 35, 41.

forms, xerogels are found as dry acrylamide/agarose copolymer sheets (Geliperm dry), or dry flake material (Bard Absorption Dressing). When wetted, the dry materials revert to hydrogels.³²

Hydrogels are water polymer gels, and are prepared as 3-D networks of hydrophilic polymers such as gelatin, polysaccharides, cross-linked polyacrylamide polymers, polyelectrolyte complexes, and polymers or copolymers of methacrylate esters. They have a high moisture content which maintains a moist interface, aids cell migration and prevents dressing adherence. The gels swell in a three-dimensional manner when they absorb fluid. They are permeable to water and water vapor as long as the gel is not saturated. Its mesh size allows absorption and desorption of high molecular weight proteins and low molecular weight solutes, and the high moisture content allows a dissolved oxygen permeability so that aerobic function can continue, and epithelial growth is increased. Examples are Vigilon, Sclerisorb, and Geliperm.³³

Hydrocolloids are complex formulations that contain colloid elastomeric and adhesive components, instead of single polymer hydrogels. They are flexible, elastic, adherent, semipermeable, and made of polyurethane. They are available as a paste or powder. The dressings provide a gaseous and moisture proof environmental chamber that strongly adheres to the surrounding area, which allows protection from contamination. Exudate is absorbed to form a gel, which expands into the wound cavity, increasing pressure and support. The moist gel is soft and conforms to the wound contours.³⁴ Its gaseous impermeability leads to a slightly acidic and hypoxic environment which encourages rapid angiogenesis and neovascularization. Therefore this dispersive gel has both fibrolytic and angiogenic activity.³⁵ However, sometimes they can not absorb wound exudates fast enough. These dressings should therefore be used in the later stages of healing when drainage has decreased.³⁶

3.4 Biologic Dressings

Biologic dressings, by reasons that are not completely understood, lower bacterial counts in wounds. They serve as temporary skin replacements, promoting a less painful wound, and

³²Krasner 35.

³³Krasner 36.

³⁴Krasner 37-38.

³⁵Krasner 41.

³⁶Krasner 305-307.

preventing heat and protein loss. Pigskin, cadaver skin grafts, amnion, and the patient's own skin can be used to cover the wound temporarily. In actuality three materials are commonly used. These are human cadaveric allograft skin, also called "homograft" and is available from 43 skin banks in the United States, porcine xenograft skin, also called "heterograft" and is available from a single supplier, Bioplast, Inc., St. Paul, MN, and human amniotic membranes, which are available from obstetrical services but need to be cleansed.³⁷

Cadaveric allograft skin was first used as a method to temporarily cover wounds with a viable skin transplant after removal of non-viable tissue. Allograft closure of wounds reduce loss of heat, water, electrolytes, and protein, and act as a barrier to microbial invasion of the wound. Cadaver skin is the dressing of choice for grafting full-thickness thermal wounds and is also used for temporary coverage of partial-thickness burn wounds and pressure ulcers. Allograft skin is held in place with surgical net, large-mesh gauze, or adhesive tape until it has "taken" to the wound. Allografts remain in place for one to two weeks, when they are removed to allow autografting of the wound. Cadaveric allograft skin must be viable and microbially clean. One item of concern is transmission of Acquired Immune Deficiency Syndrome (AIDS) through transplantable skin, but so far in the United States no transmission has been reported.³⁸

Less than 20 percent of the need for cadaveric allograft skin is met in the United States per year, so frozen porcine xenograft is used as a substitute. Adherence of the xenograft to the skin is responsible for the antibacterial effect of this dressing. Porcine xenograft does not elicit significant cellular inflammatory response, humoral antibody production, or sensitization in the recipient. The advantage of xenograft is that rapid wound healing is achieved, pain and infection are reduced, and it is readily available. However, occasionally it is incorporated into the wound bed, which delays healing and infection associated with the skin might be transferred to the wound. Recently, a $AgNO_3$ impregnated porcine xenograft has been developed, and it provides a solution to the infection problem associated with porcine skin. However, there is still some debate over the use of $AgNO_3$ in wound healing.³⁹

³⁷Krasner 303.

³⁸Krasner 303-304.

³⁹Krasner 304.

Amniotic membranes are used for temporary coverage of debrided wounds because of their ease of acquisition. However, these membranes are not as useful as wound covers as actual skin because they are too thin to adequately protect against fluid loss and microbial invasion. Amniotic membranes are fragile and need to be monitored and replaced frequently.⁴⁰

3.4.1 Skin Grafts and Flaps

Skin grafts have been used to cover open wounds when spontaneous healing by second intention would be very slow or would cause heavy scarring. In major full-thickness burns, skin grafts are absolutely necessary.⁴¹

Skin grafts are also termed autografts, because skin is moved from one position to another on a person's body. Skin graft from one person to another do not survive except for the case of identical twins.⁴²

Two types of skin grafts are present. These are split-thickness grafts and full-thickness grafts. In split-thickness grafts, the donor site keeps the lower layers of skin so the site can heal itself by epithelialization. Full-thickness grafts remove all of the skin and its appendages from the donor site, leaving a big hole since the graft is being used to close. Because of this problem, full-thickness grafts are only used when the donor site can be closed properly and when they are more useful than split-thickness grafts. The advantages of full-thickness grafts are that they do not shrink or contract much, they are better for matching colors, and they are more durable.⁴³

Split-thickness skin grafts can be of a full range of thicknesses. Thinner grafts are chosen to cover large areas or when rapid healing of the donor site is wanted. Split-thickness skin grafts are frequently used on severe burns because early skin cover and quick donor-site healing is vital. Thin grafts also take more often on non-optimal recipient sites. However, thin split-thickness grafts contract with healing, and this can produce deforming webbing. Also thin split-thickness grafts are not very durable. The thicker a split-thickness graft, the more it is like a full-thickness graft, and the slower the healing of the donor-site. Thick

⁴⁰Krasner 304.

⁴¹Finley 31.

⁴²Finley 31.

⁴³Finley 31.

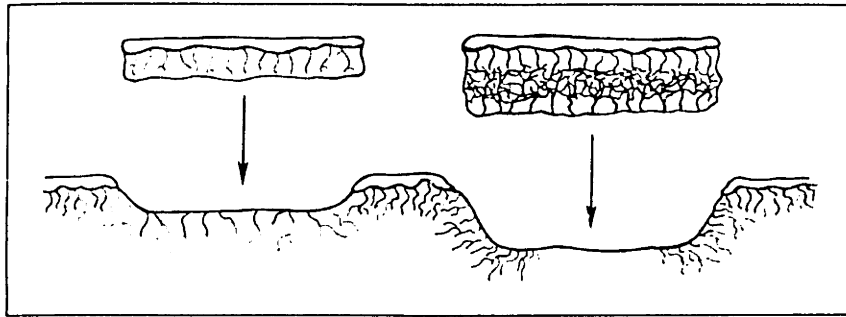


Figure 3-4: Thin vs. Thick Split-Thickness Grafts

split-thickness skin is used when the cosmetic result is important.⁴⁴ Also, better bridging occurs in thick split-thickness skin grafts than in thin grafts. Thin grafts are used with wounds that have a uniformly poor circulation, while thicker grafts are used in avascular areas (Figure 3-4⁴⁵).⁴⁶

The donor site of a thick graft is prone to complications such as slow healing, permanent scarring, and discoloration. In extreme cases, scar hypertrophy may occur, and if this seems to be occurring, constant external compression should be applied with an elastic garment. Skin should therefore be taken from areas usually concealed by clothing.⁴⁷

The graft itself should be treated by the open method or with frequently changed occlusive dressings in wounds that are heavily contaminated. These allow frequent observation of the graft and also allow drainage of fluid accumulation which would hinder graft survival.⁴⁸

Recently, meshed skin has been developed by putting thin split-thickness skin through a device to punch many holes in it so that it resembles a fish net. The advantages of meshed skin are that it increases the area that the graft can cover and it also allows free drainage of fluids. However, it looks like a net, even when completely healed, and it contracts excessively. Meshed grafts should be dressed with thick occlusive dressings to absorb the expected drainage and should be changed often to keep the wound clean until the skin has taken and the holes in the mesh have epithelialized completely.⁴⁹

Skin flaps are much more versatile than skin grafts because the skin has an intact blood

⁴⁴Finley 31-32.

⁴⁵Rudolph 68.

⁴⁶Rudolph 68.

⁴⁷Finley 32.

⁴⁸Finley 32.

⁴⁹Finley 32-33.

supply and underlying soft tissue. When direct approximation is impossible, the first choice of a surgeon is the skin graft, but sometimes the conditions require a skin flap. Flaps are used when a skin graft would not suffice or survive. This occurs when the bed has no blood supply. A skin flap brings its own blood supply and does not depend on the ingrowth of vessels from the recipient site for its survival. Flaps also provide a fatty or subcutaneous tissue cover. Flaps are used for their bulk which can fill up wounds. Flaps also have a cosmetic advantage, in being able to match appearance. Therefore they are often used on the face. Flaps provide padding and so they are used on weight bearing surfaces. And finally they may bring sensory innervation or sensation with them.⁵⁰

Skin flaps can be categorized in one of four categories. Random skin flaps depend on a tenuous blood supply. All circulation is from a small vessel plexus in dermis and fat. A flap can be made thin or thick. Axial skin flaps are well supplied by large vessels running along their axis. They are thicker than random flaps to preserve the large vessel and can also be much longer. Muscle flaps are similar to axial flaps because they have a linear blood supply starting at the muscle base. And finally, myocutaneous flaps supply the overlying skin by perforating vessels coming from the underlying muscle. These flaps are usually very bulky and can be longer than axial flaps (Figure 3-5⁵¹).⁵²

Postoperative management of even large flaps is uncomplicated and undelayed and common suction drains and normal dressings, even with some pressure, can be used without fear of compromising the blood supply.

⁵⁰Finley 33.

⁵¹Rudolph 72.

⁵²Finley 33.

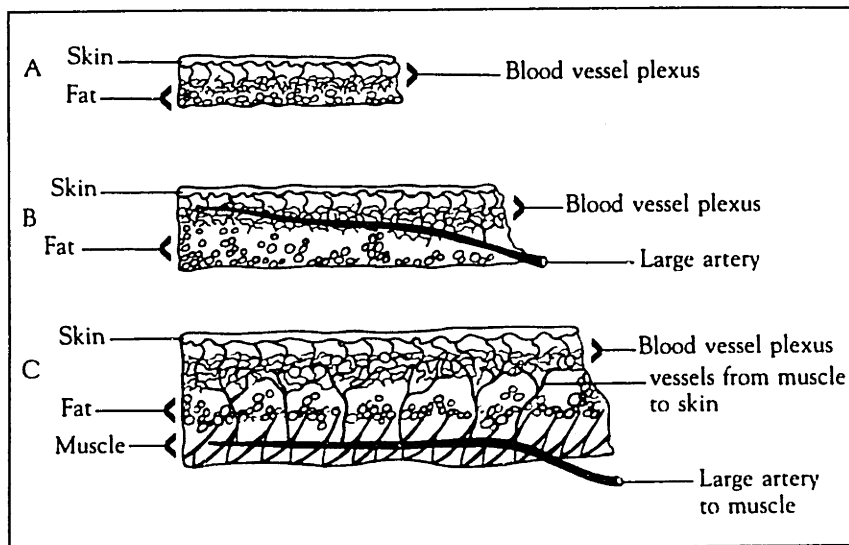


Figure 3-5: Types of Flaps for Wound Construction. A. Random Skin Flap. B. Axial Skin Flap. C. Myocutaneous Flap.

Chapter 4

Sutures and Suturing

Sutures are the most common means of approximating divided edges of skin. A suture is a strand of material used to ligate blood vessels and to approximate tissues together. The selection of suture material depends on healing characteristics of the tissues to be approximated, the condition of the wound, the probable postoperative course, and the physical and biological properties of the suture material.¹

A suture should be as strong as the tissues that are sutured, but doesn't need to be any stronger. Therefore, the tensile strength is very important. Sutures should also be the smallest size possible for the desired holding power to minimize tissue reaction to sutures. The smaller the size of the suture, the less tensile strength the strand will have. Size denotes the size of the diameter and tensile strength is measured as the force in pounds that the strand will withstand before it breaks.²

All suture materials are foreign bodies, and if uncomplicated by infection or trauma, the acute cellular tissue response changes after three days. Monocytes, plasma cells, and lymphocytes replace neutrophils and blood vessels infiltrate the area. Fibroblasts and connective tissue grow. Along with these effects, cellular enzyme activity grows. The level of lysosomal enzyme synthesis depends on whether a mild reaction is occurring, as with most suture materials, or more severe reactions are occurring due to more irritant materials. Some suture materials are more inert than others in later phases of wound healing.³

¹ *Wound Closure Manual: Use and Handling of Sutures, Needles, and Mechanical Wound Closure Devices* (New Jersey: Ethicon, Inc., 1985) 9.

² *Wound Closure Manual* 9.

³ *Wound Closure Manual* 9.

4.1 Suture Materials

A suture must have several qualities. A suture must have high uniform tensile strength which would allow the use of finer sizes; a suture must have a consistently uniform diameter per size; a suture must be pliable for ease of handling and for knot security; a suture must perform predictably; a suture must have optimal tissue acceptance by being free from irritating substances and being as inert as possible; and of course, a suture must be sterile.⁴

The choice of which suture material to use is dependant on many factors especially the rate of healing, the tensile strength of the suture, and the tissues involved. There are several choices of suture materials available after these factors are taken into account. Selection can then be made according to the familiarity of the material and the ease of handling, or other subjective preferences.⁵

All suture materials are foreign bodies to human tissue. Tissue enzymes attempt to rid themselves of the presence of foreign substances. Sutures that are broken down by these enzymes are called absorbable sutures. The absorbable suture strand is attacked and broken down by enzymes and eventually it is dissolved or digested. Suture materials that can not be dissolved by tissue enzymes are called nonabsorbable sutures. Nonabsorbable strands become encapsulated or walled off. Nonabsorbable tissues remain where they are, buried within the tissues. When used exteriorly, they must be removed postoperatively. In summary, absorbable sutures serve a temporary function while nonabsorbable sutures are permanent.⁶

Sutures can also be divided into two other categories: monofilament and multifilament. Monofilament sutures are made of single stands while multifilament sutures are made of several strands twisted or braided together. The advantages of monofilament sutures are that they resist harboring microorganisms and they tie down smoothly. Multifilament sutures on the other hand are easy to handle and have good tying qualities. However, there may be variability in knot strength among multifilament sutures due to braiding and twisting.

⁴ *Wound Closure Manual* 15.

⁵ *Wound Closure Manual* 15.

⁶ *Wound Closure Manual* 15.

4.1.1 Absorbable Sutures

The United States Pharmacopeia (U.S.P.) defines an absorbable suture as

a sterile strand prepared from collagen derived from healthy mammals or a synthetic polymer. It is capable of being absorbed by living mammalian tissue, but may be treated to modify its resistance to absorption. It may be impregnated or coated with a suitable antimicrobial agent. It may be colored by a color additive approved by the Federal Food and Drug Administration (F.D.A.)⁷

The tensile strength retention and the absorption rate are two important characteristics that describe the in vivo performance of absorbable sutures. Tensile strength loss rate and suture absorption rate are separate events. A suture can lose tensile strength rapidly and absorb slowly or it may retain tensile strength and then absorb rapidly. Figure 4-1⁸ shows the breaking strength remaining and absorption profiles of Ethicon brand absorbable sutures. The absorption process demonstrates an almost linear loss of tensile strength for the first several weeks and then is followed by loss of suture mass during the second stage of absorption. Figure 4-2⁹ shows the loss of strength in comparison to loss of volume of absorbable sutures. Specific patient conditions such as high body temperature, increased infection, and protein deficiency may enhance rapid decline in tensile strength and rapid absorption of sutures. Absorbable sutures should not be used where extended approximation under stress is desired.¹⁰

Natural Collagens

Surgical Gut Absorbable surgical gut sutures are classified as either plain or chromic. Both plain and chromic surgical gut sutures are made of the submucosa of sheep intestine or the serosa of beef intestine and are processed strands of highly purified collagen. However, chromic gut is prepared so that it has a greater resistance to absorption.¹¹

The percentage of collagen in the suture is the direct determinant of its tensile strength and its ability to be absorbed by the body without any adverse reaction. Noncollagenous

⁷ *Wound Closure Manual* 16.

⁸ *Wound Closure Manual* 17.

⁹ Stephen Karran, *Controversies in Surgical Sepsis* (New York: Praeger Publishers, 1980) 47

¹⁰ *Wound Closure Manual* 16.

¹¹ *Wound Closure Manual* 16-17.

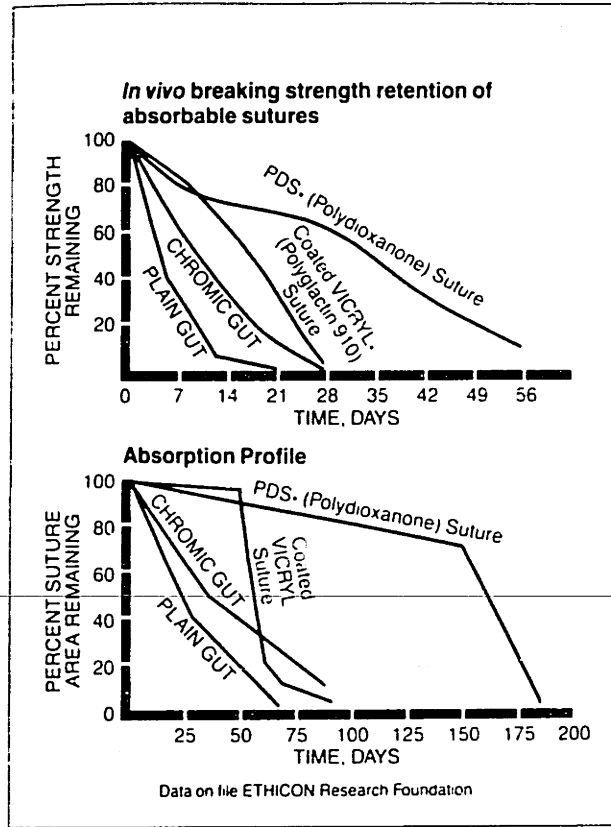


Figure 4-1: Breaking Strength Retention and Absorption Profiles of Ethicon Absorbable Sutures

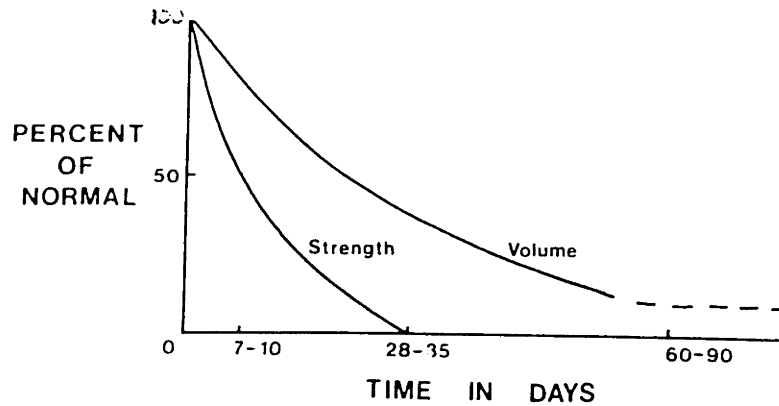


Figure 4-2: Loss of Strength and Volume of Absorbable Sutures

material may cause a reaction that may irritate or reject the suture. The rate of absorption is determined by the type of surgical gut, the type and condition of the tissue, and the conditions of the patient. Surgical gut suture absorption is controlled by cellular and tissue proteases. White blood cells attack the suture and secrete enzymes which digest the gut and cause it to lose strength and become absorbed. Biologic conditions vary the rates, and infection may increase the rate of absorption.¹²

Plain gut is not treated with chromium salts and so it is digested within 70 days, though tensile strength is maintained for only seven to ten days. It can be used in tissues that heal rapidly and do not need much support while healing. Plain gut is mainly used for suturing subcutaneous fatty tissue and ligating minor blood vessels.¹³

Fast absorbing plain surgical gut is specially heat treated to speed up the rate of tensile strength loss and absorption. It is designed for epidermal suturing which requires sutures for only five to seven days. Interrupted sutures are placed in the skin and skin closure tape is placed lengthwise over the incision. The tape is removed in five to seven days, and the knots and suture on the outside of the skin lift up with the tape because underlying sutures have been digested. This variety of plain surgical gut suture has less tensile strength than plain surgical gut suture and should not be used internally.¹⁴

Chromic gut is treated in a chromium salt solution which makes it more resistant to enzymes, and extends absorption time to over 90 days. Chromic gut is used in tissues that need longer support and heal somewhat slowly such as the fascia and peritoneum. It is less irritating and therefore causes less tissue reaction in the early stages of wound healing. Tensile strength is maintained for ten to 14 days and measurable strength remains for up to 21 days.¹⁵

Collagen Suture Collagen sutures are extruded from a homogeneous dispersion of pure collagen fibers from the flexor tendons of beef and are chemically treated to remove non-collagenous materials. These sutures have a similar appearance to surgical gut but have physical properties superior to surgical gut. For example, collagen sutures have inherent plastic deformity that cause the material to flatten out at the knot which is a benefit for oph-

¹² *Wound Closure Manual* 17.

¹³ *Wound Closure Manual* 17.

¹⁴ *Wound Closure Manual* 17.

¹⁵ *Wound Closure Manual* 17-18.

thalmic surgery. Collagen sutures produce minimal tissue reaction, are uniformly absorbed within 56 days and tensile strength is measurable for up to ten days.¹⁶

Synthetic Absorbable Sutures

Polyglactin 910 Suture Polyglactin 910 is a copolymer of lactide, which is from lactic acid, and glycolide, which is from glycolic acid. Both lactic acid and glycolic acid exist in the body naturally, as products of the metabolic processes. Lactide has a water repelling quality that slows down the penetration of water into the sutures filaments, and therefore slows down the rate of tensile strength loss in the body as compared to sutures that are enzymatically absorbed and digested. Lactide groups are also bulky, so the polymer chains that make up the filaments are kept spaced apart so that absorption of the suture is rapid, after the strength is lost. The combination of lactide and glycolide at the correct proportions allows tensile strength to be maintained for efficient approximation during the critical period, after which absorption occurs rapidly.¹⁷

About 60 percent of the original tensile strength is remaining after 14 days and about 30 percent is remaining after 21 days. Absorption is negligible until 40 days, and is complete between 60 and 90 days.¹⁸

Absorption occurs by slow hydrolysis in the presence of tissue fluids. Only water is required for the breaking down the polymer chains. Enzymes are not required, so these sutures show a lower tissue reaction than surgical gut. Water gradually penetrates the filaments of the suture and the polymer chains break down.¹⁹

The copolymer is extruded into monofilament strands which may be dyed so that visibility in tissue is enhanced, or is also found undyed or natural. These sutures are used in ophthalmic surgery. These monofilament strand may also be braided or coated.²⁰

Coated Polyglactin 910 Suture Braided polyglactin 910 monofilament sutures are coated by a mixture of equal parts of a copolymer of glycolide and lactide (polyglactin 370) and calcium stearate. Calcium stearate is a salt of calcium and stearic acid, both of which are present in the body and are metabolized and excreted. The combination of the two

¹⁶ *Wound Closure Manual* 18.

¹⁷ *Wound Closure Manual* 18.

¹⁸ *Wound Closure Manual* 18.

¹⁹ *Wound Closure Manual* 18.

²⁰ *Wound Closure Manual* 18.

compounds produce an absorbable, adherent, non-flaking lubricant. The lubrication allows smooth passage through the tissue to minimize drag, precise knot placement, and smooth tie down. The coating absorbs quickly within 90 days and is inert, nonantigenic, and produce only a mild tissue reaction. Rate of loss of tensile strength and absorption are consistent with uncoated monofilament polyglactin 910 sutures. Coated polyglactin 910 sutures may be used in the presence of infection because they are similar to monofilament sutures in construction. These sutures are also found in both the dyed and natural varieties, in several lengths and with or without needles.²¹

Polydioxanone Suture Polydioxanone suture is a monofilament, absorbable suture, made from the polyester, poly (p-dioxanone) and is useful when an absorbable suture with wound support for up to six weeks is needed. About 70 percent of the original tensile strength is remaining after two weeks, 50 percent at four weeks, and 25 percent at six weeks. Polydioxanone sutures provide wound support twice as long as any other synthetic absorbable suture. Absorption is minimal until ninety days and is complete by six months during which only a slight tissue reaction is provoked. Polydioxanone suture is absorbed by hydrolysis.²²

The polymer contains an oxygen ether group which allows softness and pliability to the monofilament design. These sutures may be used in the presence of infection and is nonantigenic and nonpyrogenic. These sutures are also available in clear and dyed varieties.²³

4.1.2 Nonabsorbable Sutures

The U.S.P. defines nonabsorbable sutures as

strands of material that are suitably resistant to the action of living mammalian tissue. A suture may be composed of a single or multiple filaments of metal or organic fibers rendered into a strand by spinning, twisting, or braiding. Each strand is substantially uniform in diameter throughout its length within U.S.P. limitations for each size. The material may be uncolored, naturally colored, or dyed with an F.D.A. approved dyestuff. It may be coated or uncoated; treated

²¹ *Wound Closure Manual* 18-19.

²² *Wound Closure Manual* 19.

²³ *Wound Closure Manual* 19.

or untreated for capillarity.²⁴

Capillarity is the quality that allows tissue fluids to pass along the strand, allowing any present infection to be drawn along the suture strand.²⁵

Class I nonabsorbable sutures are made of silk or synthetic fibers and may be monofilament, braided, or twisted. Class II nonabsorbable sutures are made of linen, cotton, or coated natural or synthetic fibers, and the coating forms a casing of some thickness but does not affect the tensile strength much. Class III nonabsorbable sutures are monofilament or multifilament metal wire.²⁶

Since nonabsorbable sutures are not absorbed or digested, they must be removed post-operatively when placed in surface tissues. When they are buried within the body, they become encapsulated or permanently surrounded by tissue.²⁷

Natural Nonabsorbables

Surgical Silk Surgical silk is the most widely used nonabsorbable suture material because of its historical use, and handling properties. Silk can be twisted or braided, and the braided variety is preferred because of its handling qualities. Raw silk is a continuous filament spun by the silkworm larva in making its cocoon, and is graded according to strength, uniformity of diameter, and freedom from defects. Filaments from several cocoons are combined to produce the many different varieties and sizes of sutures. Raw silk is cream or orange, and is processed to remove natural waxes or gums that the silkworms produce to hold the cocoon together. The untreated silk also has capillary action, so it is treated to reduce the capillarity. The silk is also dyed for easy visibility. It is used dry because it loses tensile strength when exposed to moisture. The U.S.P. classifies silk as nonabsorbable but within one year it loses almost all of its tensile strength and within two years the strand is absorbed. So in reality, it is a very slowly absorbable suture.²⁸

Virgin Silk Virgin silk suture is several natural silk filaments twisted together, of very small diameter. It is used in ophthalmic surgery. The sericin gum is not removed and

²⁴ *Wound Closure Manual* 19.

²⁵ *Wound Closure Manual* 19.

²⁶ *Wound Closure Manual* 19.

²⁷ *Wound Closure Manual* 19.

²⁸ *Wound Closure Manual* 20.

actually holds the filaments together. Virgin silk allows placement of fine sutures and very small knots, but it must be carefully handled. Virgin silk may be temporarily dyed to enhance visibility with methylene blue.²⁹

Surgical Cotton Surgical cotton sutures are made from individual long staple Egyptian cotton fibers that are combed and twisted. The strand must undergo a chemical purification process. The natural fiber contains cellulose, and impurities such as waxes, pectins (gums), nitrogenous substances (vegetable protein matter), pigments, and mineral matter (sand). Mild detergents and dilute alkali solutions are used to remove the impurities and bleach finally whitens the thread. The strand is coated to smooth the surface. Cotton sutures are the weakest of the nonabsorbable sutures but gain tensile strength when wet. These sutures are moistened before use.³⁰

Linon Linon sutures are made from twisted long staple flax fibers and are sometimes used in gastrointestinal surgery. The diameter of linon strands is difficult to control and tensile strength is inferior to other nonabsorbable sutures.³¹

Surgical Stainless Steel Surgical stainless steel sutures must be free of toxic elements, flexible and fine. The steel alloy most commonly used is 316L (low carbon) and is a specially formulated iron-nickel-chromium alloy. It produces sutures with optimal metal strength, flexibility, uniformity, and compatibility with stainless steel implants and prostheses. It should not be used with prostheses of other alloys because of the risk of an unfavorable electrolytic reaction. Stainless steel sutures are inert, have high tensile strength and are available as both monofilament and multifilament. Steel is used for abdominal wall closure, sternal closure, retention and skin closure, tendon repair, and some other orthopedic procedures and neurosurgery. However steel sutures are difficult to handle, don't hold knots well, may corrode, fragment, or pull or tear tissue if tied too tightly.³²

²⁹ *Wound Closure Manual* 20.

³⁰ *Wound Closure Manual* 20.

³¹ *Wound Closure Manual* 20.

³² *Wound Closure Manual* 20-21.

Synthetic Nonabsorbables

Nylon Sutures Nylon is a polyamide polymer that is derived by chemical synthesis and is extruded into a noncapillary monofilament strand. It has high tensile strength and low tissue reaction. It degrades in vivo at a rate of fifteen to twenty percent a year by hydrolysis. Monofilament sutures are more pliable and easier to handle when wet and have a tendency to return to their original straight state. Braided nylon resists this tendency more. Nylon is suited for retention and skin closure because of its elasticity. It is available in clear or dyed varieties. Very fine sizes are also used in ophthalmology and microsurgery.³³

Braided nylon sutures are treated for noncapillarity and come in white or dyed. It looks, feels and handles like silk but is stronger and produces less tissue reaction. Braided nylon sutures can be used in all tissues that require a multifilament, nonabsorbable suture. These sutures also lose tensile strength at the same rate as the monofilament nylon sutures.³⁴

Polyester Fiber Sutures Polyester fibers (polyethylene terephthalate) are braided together and are stronger and produce less tissue reaction than natural nonabsorbable sutures. These sutures are available untreated, which cause a higher coefficient of friction when passed through tissue, or may be coated with polybutylate, a highly adherent coating that acts as a lubricant. This coating is inert, nonabsorbable, and also improve pliability and handling qualities. It is a polyester material that adheres strongly to braided polyester fiber strands, both of which are pharmacologically inactive. Both types of sutures produce minimal tissue reaction. They are braided for better handling, and are available in white or dyed. Polybutylate coating also improves the knot tying qualities. Polyester sutures are used in cardiovascular surgery for vessel anastomosis, and placement of vascular synthetic prostheses because it retains its strength in vivo for extended periods. The coated polyester sutures are also available attached to teflon felt pledgets which are used as buttresses under sutures when there is a possibility of adjacent friable tissue tearing. These are usually used in heart valve replacement procedures to prevent the annulus from tearing when the prosthetic valve is placed and tied.³⁵

³³ *Wound Closure Manual* 21.

³⁴ *Wound Closure Manual* 21-22.

³⁵ *Wound Closure Manual* 22.

Polypropylene Sutures Polypropylene is an isotactic crystalline stereoisomer of a linear hydrocarbon polymer with little or no unsaturation. It is manufactured to enhance pliability and handling. It may be clear or dyed. This suture is not degraded or weakened by tissue enzymes. It is extremely inert, has high tensile strength, causes little tissue reaction, and holds knots better than other synthetic monofilament materials. It does not adhere to the tissue so it may be pulled out. It is widely used in general, cardiovascular, plastic, and orthopedic surgery. It is also used in contaminated and infected wounds to minimize later sinus formation and suture extrusion.³⁶

4.1.3 A Comparison of Sutures

The choice of a suture partly depends on the strength of the suture, which determines the size of the suture used (Figure 4-3³⁷). Another important quality that determines the suture material used is the degree of tissue irritation elicited by the suture because this is an important determinant of wound infection (Figure 4-4³⁸). In general the natural materials are most irritating and the synthetic monofilaments are the least. Polyglycolic and polyglactin absorbable sutures and nylon and polypropylene nonabsorbable sutures have the least potentiating effect of all the sutures. They are followed by plain gut absorbable sutures and coated and uncoated dacron nonabsorbable sutures and then by chromic gut absorbable sutures and metal nonabsorbable sutures. Finally silk and cotton have the most infection potentiating effect.³⁹

4.2 Suturing Techniques

Suturing is a term that includes any method of approximation of tissues or ligation with a strand of material. Many variations are possible in placing sutures and tying knots.

4.2.1 Ligatures

A ligature is a suture tied around a vessel to occlude the lumen. Ligatures are used for hemostasis or for closing off a structure to prevent leakage. There are two methods of

³⁶ *Wound Closure Manual* 22.

³⁷ Karran 46.

³⁸ Karran 47.

³⁹ Richard F. Edlich, John G. Thacker, George T. Rodeheaver, and Milton T. Edgerton. *A Manual For Wound Closure* (Minnesota: Minnesota Mining and Manufacturing Co., 1980) 30.

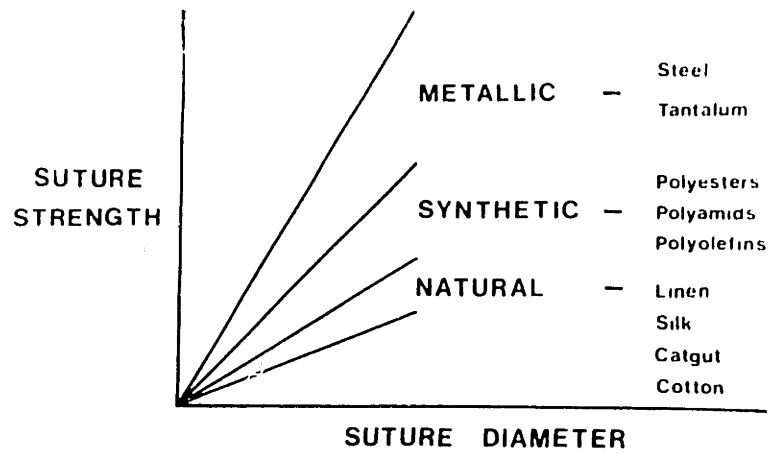


Figure 4-3: Suture Strength of Various Suture Materials vs. Suture Diameter

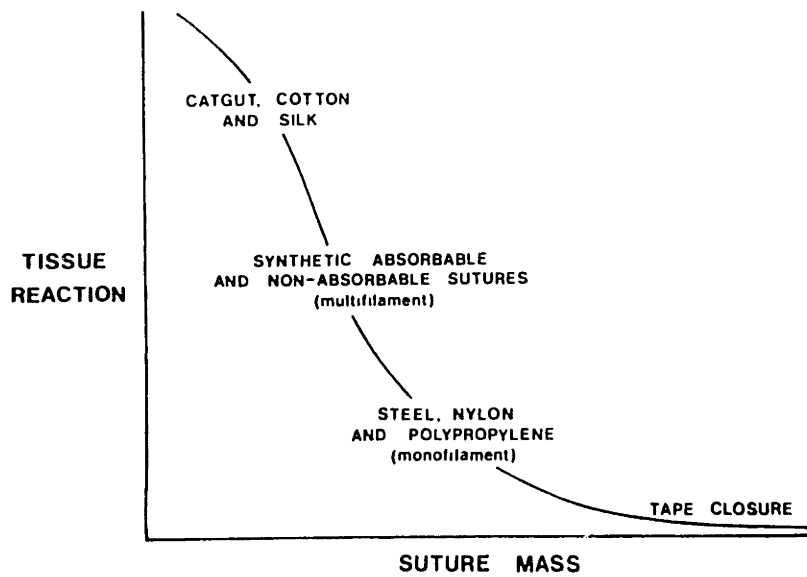


Figure 4-4: Tissue Reaction of Various Suture Materials vs. Suture Mass

ligation: free tie and stick tie. A free tie is a single strand of material that is used to ligate a vessel. A hemostat is placed on the end of the vessel and the suture is tied around the vessel under the tip of the hemostat. The knot is tightened by fingers or forceps. A stick tie, also called a suture ligature or transfixion suture, is a strand of material that is attached to a needle. The needle is used to anchor the strand in tissue and then a large vessel may be occluded.⁴⁰

4.2.2 Primary Suture Line

The primary suture line relates to sutures that hold wound edges close to each other during healing by first intention. These sutures can be one continuous strand of suture material or several interrupted suture strands as shown in Figure 4-5⁴¹. Several techniques exist to place sutures in strands.⁴²

Continuous Suture

A continuous suture involves taking a series of stitches with one strand of material tied only at each end of the strand. It is also called a running stitch and may be placed quickly. A continuous suture is strong because tension is evenly distributed throughout its length. It does not strangulate the tissue if it is placed with firm, but not tight, tension, and leaves less foreign body mass in the wound. However, if a continuous suture breaks, the whole line disrupts.⁴³ There are various techniques for applying continuous sutures but the most common ones are shown in Figure 4-6.

Interrupted Suture

An interrupted suture involves cutting and tying each stitch after inserting the strand through the tissue. This is the most widely used technique even though it takes longer to place than the continuous suture. If an interrupted suture breaks or loosens, the rest of the sutures might still hold the wound together. Also, in the presence of infection, microorganisms are less likely to travel along the primary suture line of interrupted stitches.⁴⁴

⁴⁰ *Wound Closure Manual* 10-11.

⁴¹ *Wound Closure Manual* 11.

⁴² *Wound Closure Manual* 11.

⁴³ *Wound Closure Manual* 11.

⁴⁴ *Wound Closure Manual* 11.

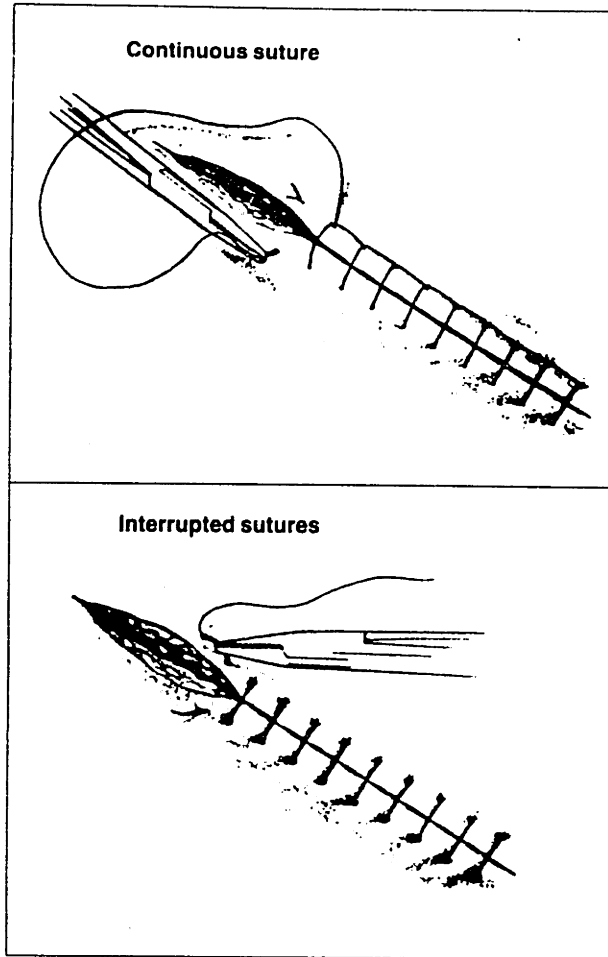


Figure 4-5: Continuous vs. Interrupted Sutures

There are various techniques for applying interrupted sutures but the most common ones are shown in Figure 4-6⁴⁵ along with the common continuous suture techniques.

Buried Suture

Buried sutures are sutures placed completely under the epidermal layer of the skin and are not removed postoperatively. Buried sutures can be both continuous or interrupted.⁴⁶

Purse-string Suture

A purse-string suture is a continuous suture placed around a lumen and tightened like a draw-string to invert the opening. A purse-string suture may be placed around the stump of the appendix, to secure an intestinal stapling device in the bowel, or in an organ just before inserting a drainage tube.⁴⁷

Subcuticular Suture

A subcuticular suture is a continuous suture placed in the subcutaneous tissue, beneath the epithelium, in a line parallel to the wound to close the skin. The suture is anchored at one end of the wound with a conventional tie or perforated lead shot. Short lateral stitches are made along the length of the wound, the suture is drawn taut and the far end is anchored just as the near end.⁴⁸

4.2.3 Secondary Suture Line

The secondary suture line refers to sutures that are placed to support the primary suture line, get rid of dead space, or prevent suture accumulation in the abdominal wound during healing by first intention. These sutures are placed two inches away from each edge of the wound and the lateral tension exerted adds to the tensile strength of the wound. Sutures used for this reason are called retention, stay, or tension sutures and are also used to support wounds healing by second intention, or for secondary closure after wound disruption for wounds healing by third intention.⁴⁹

⁴⁵ *Wound Closure Manual* 13.

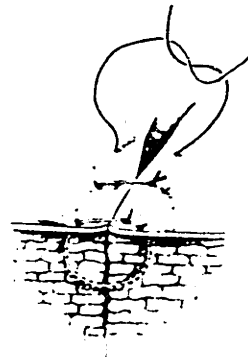
⁴⁶ *Wound Closure Manual* 11.

⁴⁷ *Wound Closure Manual* 11.

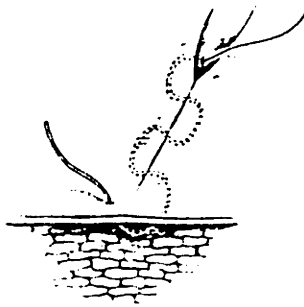
⁴⁸ *Wound Closure Manual* 11.

⁴⁹ *Wound Closure Manual* 12.

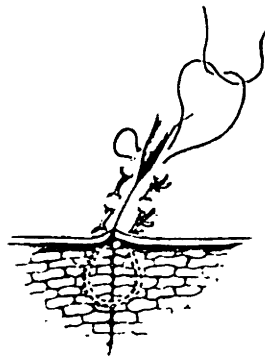
Common suturing technics



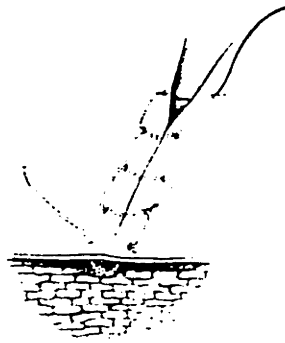
Simple Interrupted



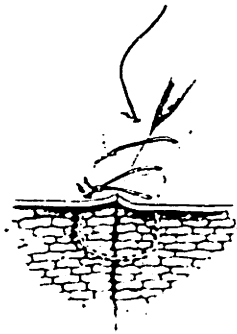
Interrupted Vertical Mattress



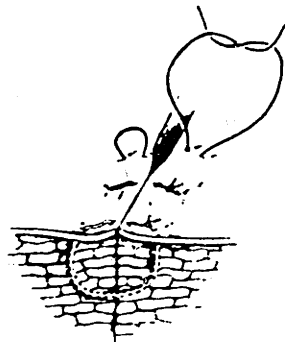
Interrupted Horizontal Mattress



Continuous Horizontal Mattress



Continuous Over and Over



Continuous Subcuticular

Figure 4-6: Common Suturing Techniques

Through-and Through Retention Suture

Through and through retention sutures are placed from the inside of the peritoneal cavity through all the layers of the abdominal wall, including the peritoneum, and are placed before the peritoneum is closed. These stitches are either interrupted or figure-eight. The wound is closed in layers for about 3/4's of the length and the retention sutures in this area are drawn together and tied. The rest of the wound is closed similarly. Strangulation of the viscera during closure should be prevented by placing a finger in the abdominal cavity.⁵⁰

Buried Coaption-Retention Sutures

The peritoneum is closed with interrupted sutures and retention sutures are placed to penetrate only the layers from the fascia to the skin. The retention sutures are placed about two centimeters apart in the peritoneum and the rest of the wound is closed in layers and retention sutures are tied.⁵¹

4.2.4 Placement of Stitches

Many types of stitches are used for both continuous and interrupted suturing. But for all types of stitches, equal amounts of tissue should be taken from each side of the wound and the distance from the point of needle insertion to the wound depends on the tissue. The distance from one suture to the next should be approximately equal to the distance from the edge of the wound to the suture. Most tissues heal when the edges are approximated but sometimes the tissues should be either inverted or everted. The mucosa in a sutured gastrointestinal anastomosis is inverted, opposing serosa to serosa, and skin edges are sometimes everted.⁵²

4.2.5 Knot Security and Knot Tying

There are certain qualities in a suture that affect knot security and tying. Hand is the feel of the suture and the smoothness of passage through the tissue and tying down. Extensibility is the stretching of the suture during knot tying and subsequent recovery. This characteristic signals the surgeon when the knot is snug. Memory is the built-in orienta-

⁵⁰ *Wound Closure Manual* 12.

⁵¹ *Wound Closure Manual* 12.

⁵² *Wound Closure Manual* 12.

tion of the polymer of synthetic monofilament sutures produced by stretching the filament during extrusion. This quality increases the risk of knot slippage. When knot security is crucial, synthetic multifilament sutures are used and additional knots are tied to maximize knot security. Knots do not tend to slip with multifilament sutures because the braided or twisted construction produce a high coefficient of friction.⁵³

Of the 1400 plus types of knots in the Encyclopedia of Knots, only a few knots are used in modern surgery. It is extremely important, though, that each knot placed is perfect with respect to holding tension. The knot used depends on the suture material and location, depth, and purpose of the suture. Knots must be tied according to the tissue and anticipated postoperative edema. Several throws might be necessary for a secure knot.⁵⁴

Eight types of knots are commonly used: granny knot, square knot, surgeon's knot square, surgeon's knot granny, reversed surgeon's knot square, reversed surgeon's knot granny, double-double knot square, and double-double knot granny (Figure 4-7⁵⁵). A square knot is formed by two single throws such that the right ear and loop are exactly opposite the left ear and loop. When the right ear and loop of the two single throws come out on different sides of the knot, it is called a granny knot. A knot is classified as a granny or square by the relationships between the ears and loops of the knot. A surgeon's knot has an initial double wrap throw superimposed by a single throw. A reverse surgeon's knot has an initial single throw followed by a double wrap throw. A double-double knot has two double wrap throws.⁵⁶

Regardless of knot type, there are some general principles for knot tying. The finished knot should be firm, with little possibility for slippage. The knot should be the simplest knot possible, small, and with the ends cut as short as possible to reduce the risk of foreign body reaction. Excessive motion or rubbing of the suture strands while tying may weaken the material of the suture and increase the risk of breaking. Finer gauge materials should be used without great tension. The two ends of the suture should be pulled in opposite directions with uniform rate and tension when tying for secure knots and lower probability of breakage. Care should be taken when using surgical instruments, so that the suture is not

⁵³ *Wound Closure Manual* 23.

⁵⁴ *Wound Closure Manual* 13.

⁵⁵ Edlich 34.

⁵⁶ Richard F. Edlich, John G. Thacker, George T. Rodeheaver, and Milton T. Edgerton *A Manual for Wound Closure* (Minnesota: Minnesota Mining and Manufacturing Co., 1980) 33.

GRANNY KNOT TYPE



Granny Knot



Surgeon's Knot Granny



Reverse Surgeon's Knot Granny



Double Double Knot Granny

SQUARE KNOT TYPE



Square Knot



Surgeon's Knot Square



Reverse Surgeon's Knot Square



Double Double Knot Square

Figure 4-7: The Configuration of Surgical Knots

crushed or crimped. Sutures for approximation should not be tied too tightly because this might cause tissue strangulation. After the first loop is tied, traction must be maintained to prevent loosening of the knot. Extra throws do not add to the strength of the knot, they only add bulk.⁵⁷

4.2.6 Cutting Sutures

Sutures are cut by running the tip of the scissors lightly down the strand to the knot. Surgical gut ends are cut relatively long, but other materials are cut close to the knot to minimize foreign material residues in the wound. The ends of the suture are removed as they are cut. Care is taken to prevent inadvertant cutting of tissues.⁵⁸

4.2.7 Suture Removal

Nonabsorbable skin sutures must be removed. They are removed form the face and neck in two to five days; Other skin sutures are removed from five to eight days; Retention sutures are removed from ten to 14 days. The area is cleansed with an antiseptic and hydrogen peroxide is used to remove dried serum around the sutures. The suture is cut on one side as close to the skin as possible, and the suture is gently pulled out the other side.⁵⁹

4.3 Suture Selection

The selection of sutures often depends on the surgical specialty and the location of the wound.

4.3.1 Sutures Needed in Abdominal Surgery

Sutures are needed immediately upon the onset of operating, for ligatures. Usually absorbable sutures are preferred for this purpose. Sutures inside the peritoneal cavity depend on the operation and the technique.⁶⁰

⁵⁷ *Wound Closure Manual* 13.

⁵⁸ *Wound Closure Manual* 14.

⁵⁹ *Wound Closure Manual* 14.

⁶⁰ *Wound Closure Manual* 27.

Sutures for the Gastrointestinal Tract

The main problem in closing wounds in the gastrointestinal tract is leakage. Leakage can cause localized or generalized peritonitis. Anastomosis without leakage can be achieved with both a single layer or double layer closure. For a single layer closure, interrupted, nonabsorbable sutures, often polypropylene, are used. Inverting, everting, or end-to-end closure techniques are all used.⁶¹

The submucosa provides the strength in the gastrointestinal tract so it must be closed with good approximation. A continuous absorbable suture provides a tighter seal than an interrupted suture, but because of breakage risks, a second layer of sutures are sometimes placed in the serosa for insurance. Silk or other nonabsorbable sutures are used when interrupted sutures are used.⁶²

Sutures should not be tied too tightly for anastomotic closure because wounds of the stomach and intestine are edematous and swell because of their rich blood supply. Tight sutures might cut through tissue and provide leakage channels.⁶³

Stomach The stomach heals rapidly with maximum strength attained in 14 to 21 days postoperatively. Collagen synthesis in the stomach peaks in five days. Therefore absorbable sutures are acceptable, but they might produce a moderate tissue reaction. Polypropylene suture material is the mildest while silk produces the greatest tissue reaction.⁶⁴

Small Intestine Closure of the small intestine has similar problems as the stomach. The proximal intestinal contents are mostly bile or pancreatic juice and leakage may cause severe chemical peritonitis. If an inverting closure technique is used, minimal tissue should protrude into the lumen to avoid obstruction of the small intestinal lumen. Absorbable sutures are preferred because they do not permanently limit lumen diameter and also because the small intestine heals rapidly, with maximal strength attained within 14 days. A nonabsorbable suture is sometimes used in the serosal layer for added insurance.⁶⁵

⁶¹ *Wound Closure Manual* 27.

⁶² *Wound Closure Manual* 27.

⁶³ *Wound Closure Manual* 28.

⁶⁴ *Wound Closure Manual* 28.

⁶⁵ *Wound Closure Manual* 28.

Colon The rate of healing for the colon is the same as the stomach and small intestine but a high rate of collagen synthesis is maintained for over 120 days. However, only a thin fibrous scar is formed. The entire gastrointestinal tract shows a loss of collagen and increased collageneous activity after colon anastomosis.⁶⁶

There is a high level of bacterial content in the large intestine and this is a potential contamination factor. Leakage is extremely serious. Polyglactin 910 absorbable sutures are used because they are absorbed within 28 days, and when absorbed, they leave no channel for bacterial migration. Single layer leak-proof anastomosis can also be performed with monofilament nonabsorbable sutures. Complications can be avoided if the sutures are placed in the submucosa and the mucosa is not penetrated.⁶⁷

Rectum The rectum heals slowly and does not have a serosa. Muscle should be included in anastomosis. Monofilament sutures should be used because of potential bacterial contamination.⁶⁸

Sutures for the Biliary Tract

The cystic and common bile ducts heal rapidly but their contents present considerations for suture use. These fluids are nearly saturated with crystalloids, and the presence of a foreign body, such as a suture, may induce precipitation. Sutures may induce stone formation in the biliary tract. Therefore nonabsorbable sutures should not be used. Monofilament absorbable sutures in fine sizes are preferred.⁶⁹

Sutures for Parenchymatous Organs

Spleen, kidney, or liver lacerations may need to be repaired to control hemorrhage or oozing. Large severed vessels within the organ must be ligated before attempting to close the laceration, or hematomas or secondary hemorrhage may occur. Sutures do not hold well in organs composed mainly of cells with little connective tissue support. The outer fibrous capsule of the organ must be coapted and small size sutures should be used because tension is minimal. If the edges can not be approximated, a thin piece of omentum should be tacked

⁶⁶ *Wound Closure Manual 2S.*

⁶⁷ *Wound Closure Manual 2S.*

⁶⁸ *Wound Closure Manual 2S.*

⁶⁹ *Wound Closure Manual 2S.*

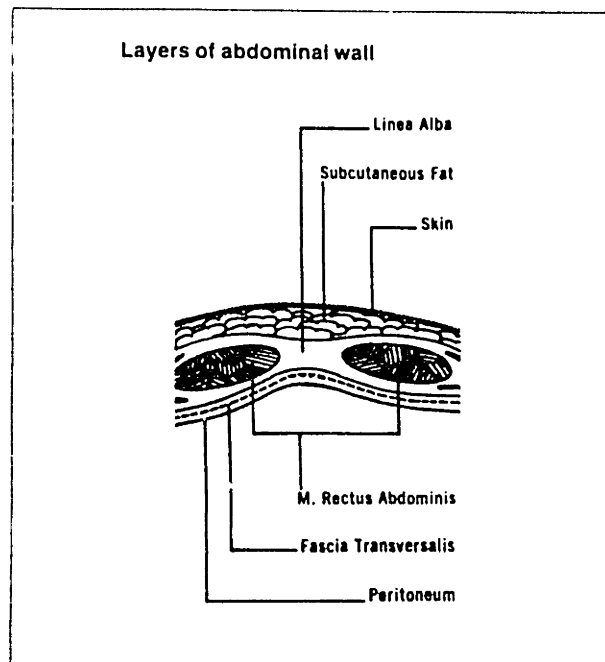


Figure 4-8: Layers of the Abdominal Wall

over the defect. Sutures don't have to be placed close together or deeply. Repair is rapid and a new fibrous capsule covers the defect within ten days. If oozing persists, the wound may be packed and drained with no attempt for primary repair.⁷⁰

4.3.2 Layered Closure

For layered closure methods, the wound is sutured in layers with sutures placed close to the tissue edges. The layers of the abdominal wall consist of the peritoneum, the fascia, muscle, subcutaneous fat, and skin, as shown in Figure 4-8⁷¹.

Peritoneum The peritoneum is a thin membranous lining of the abdominal cavity below the posterior fascia. The peritoneum heals quickly and may not need suturing at all, especially if the posterior fascia is securely closed. If the peritoneum is closed, an absorbable suture with continuous technique is preferred.⁷²

Fascia The fascia is a layer of firm connective tissue covering muscle and is the major supportive structure of the body. It is the strongest tissue in the abdominal wall and heals very slowly. Only forty percent of its original strength is regained in two months and

⁷⁰ *Wound Closure Manual* 28-29.

⁷¹ *Wound Closure Manual* 27.

⁷² *Wound Closure Manual* 29.

maximal strength is regained in more than a year. Full strength is never regained. Fascial sutures must hold the wound closed and resist changes in intraabdominal pressure. A moderate size monofilament or multifilament absorbable suture may be used in the absence of infection or a monofilament absorbable suture or an inert nonabsorbable suture such as stainless steel or polypropylene may be used in the presence of infection. Interrupted technique is usually used and care is taken to avoid strangulation. Most suture materials except steel have some elasticity and give with the tissue, if not tied too tightly. The location and type of abdominal incision influences the number of layers of fascia that are sutured. The posterior layer is always closed. Mass closure techniques however, are becoming more popular.⁷³

Muscle Abdominal muscles may be cut, split, or retracted depending on the location and type of incision. During closure, muscles handled in these manners do not need to be sutured. The fascia is sutured instead of the muscle so that muscle is not impaired in normal motion. When sutures are placed in abdominal muscle tissue, they are the same material as that used in the fascia.⁷⁴

Smead-Jones Technique The Smead-Jones far-and-near technique is also used for abdominal closure and is a single layer closure through both layers of the abdominal wall fascia, abdominal muscles, peritoneum, and anterior fascial layer. This technique uses interrupted sutures which resemble a figure-eight when placed.⁷⁵

Monofilament stainless steel or polypropylene suture is used and the closure is strong, rapid, and provides good wound support during early wound healing. One disadvantage of both types of suture, especially in thin patients, is the lump caused by knots underneath the skin, but this can be corrected by burying knots under the fascia instead of in the subcutaneous space.⁷⁶

Subcutaneous Fat Fat does not tolerate sutures well because there is little tensile strength. Some surgeons believe that a few sutures must be placed in a thick layer of subcutaneous fat to hold wound edges together, especially in obese patients. Without good

⁷³ *Wound Closure Manual* 29.

⁷⁴ *Wound Closure Manual* 29.

⁷⁵ *Wound Closure Manual* 30.

⁷⁶ *Wound Closure Manual* 30.

~~approximation, dead spaces may be left and fluids can accumulate, delaying wound healing and promoting infection. Usually absorbable material is used.~~⁷⁷

Subcuticular The subcuticular layer is tough connective tissue, and if sutured, will hold skin edges together for good cosmetic results. With single subcuticular layer closure, there is less scar gaping or expansion than with simple skin closure. Continuous short lateral stitches are taken below the epithelial layer. Either absorbable or nonabsorbable sutures may be used but if nonabsorbable sutures are used, the suture strand must come out of the skin at each end of the incision and a perforated lead shot is crushed tightly on each end to secure the suture.⁷⁸

Fine sizes may be used where skin tension is not great as in the face and neck, but larger sizes should be used for abdominal wounds. For very fine scars, close approximation of the skin is required and skin closure tapes can supplement subcuticular sutures.⁷⁹

Skin The skin is composed of epithelium and the underlying dermis. Skin wounds regain tensile strength slowly but sutures are removed between three and ten days postoperatively because the fascia supports most of the wound stress and the skin is subjected to little tension. Skin or subcuticular sutures only need to be strong enough to overcome the natural skin tension and keep wound edges in apposition. The farther apart the wound edges are, the wider the resultant scar will be.⁸⁰

Continuous or interrupted technique may be used but interrupted is preferred to reduce risk of contamination. Nonabsorbable or absorbable material may be used but both should be monofilament because the skin is exposed to exogenous microorganisms. Monofilament sutures also induce less tissue reaction than multifilament sutures and are better for cosmetic reasons. Skin edges should always be everted.⁸¹

Closure with Retention Sutures

Retention sutures provide a secondary suture line by relieving undue stress on the healing wound and obliterating dead space. Increased intraabdominal pressure can cause stress on

⁷⁷ *Wound Closure Manual* 30-31.

⁷⁸ *Wound Closure Manual* 31.

⁷⁹ *Wound Closure Manual* 31.

⁸⁰ *Wound Closure Manual* 31.

⁸¹ *Wound Closure Manual* 32.

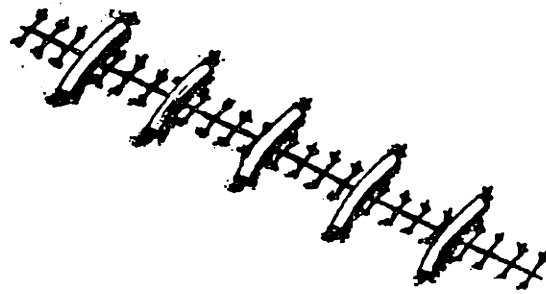


Figure 4-9: Retention Sutures With Bolsters

the primary suture line and if this is anticipated, retention sutures are used as a protection measure for possible wound disruption.⁸²

Heavy, nonabsorbable, large-sized materials are used such as nylon, polyester fiber, polyester, monofilament surgical steel and silk. The large sizes are used because they do not cut through tissue when a sudden rise in intraabdominal pressure occurs.⁸³

Retention sutures cause the patient more post operative pain than a layered closure. To prevent materials from cutting into skin under stress, one end of each retention suture may be threaded through a plastic or rubber tubing before it is tied. These pieces of tubing are called bolster or bumpers (Figure 4-9⁸⁴). Plastic bridges are also used to protect the skin and primary suture line. Retention sutures should be removed once the danger of changes in intraabdominal pressure is gone, approximately four to five days postoperatively. The increasing popularity of mass closure is leading to less use of retention sutures.⁸⁵

Sutures for Drains

A drainage tube in a hollow organ may be secured to the wall of the organ with an absorbable suture. A drainage tube into the peritoneal cavity through the abdominal wall is anchored to the skin with nonabsorbable suture to prevent it from slipping into or out of the wound.⁸⁶

⁸² *Wound Closure Manual* 32.

⁸³ *Wound Closure Manual* 32.

⁸⁴ *Wound Closure Manual* 33.

⁸⁵ *Wound Closure Manual* 32-33.

⁸⁶ *Wound Closure Manual* 33.

4.3.3 Sutures Needed in Other Body Tissues

Sutures in the Upper Alimentary Tract

The upper alimentary tract until the cardiac sphincter of the esophagus is a contaminated area. The alimentary tract is a musculomembraneous canal lined with mucous membranes.⁸⁷

Oral Cavity and Pharynx If the oral and pharyngeal structures are not infected, they heal quickly. Absorbable sutures are therefore preferred, and are also more comfortable for patients. Sometimes monofilament nonabsorbable sutures are used, but they must be removed. Wound tensions are not great, so fine sizes may be used.⁸⁸

Esophagus The esophagus is difficult to suture because it does not have a serosal layer and the mucosa heals very slowly. The thick muscular layer does not retain sutures well. Absorbable sutures are preferred and if multifilament sutures are used, the mucosa should not be penetrated to avoid infection.⁸⁹

Sutures for the Respiratory Tract

Few studies have been done on healing in the respiratory tract. Bronchial stump closure, after a lobectomy or pneumonectomy has the problem of a bronchopleural fistula forming, especially in the presence of infection, inaccurate approximation, tissue trauma, and blood supply loss. Healing of the bronchial stump is slow and sometimes nonexistent. It must be closed tightly with strong, closely spaced sutures, to prevent air leakage. Surgical steel, polyester, or polypropylene are usually used because they are the least reactive and the strongest. Monofilament sutures are the best because of the chance of infection.⁹⁰

Sutures for the CardioVascular System

Blood vessels heal rapidly but synthetic nonabsorbable sutures are preferred because of their lasting strength and the need for leak-proof anastomoses.⁹¹

⁸⁷ *Wound Closure Manual* 33.

⁸⁸ *Wound Closure Manual* 33.

⁸⁹ *Wound Closure Manual* 33.

⁹⁰ *Wound Closure Manual* 33.

⁹¹ *Wound Closure Manual* 33-34.

Vessels Luminal diameter may be decreased or thrombus formation may occur if excessive tissue reaction occurs. Therefore, inert synthetics, such as nylon, polyester, or polypropylene are used for vessel anastomoses. Multifilament polyester sutures allow clotting to occur within the interstices and this helps prevent leakage at the suture line. Coated polyester sutures cause less friction when drawn through vessels. Monofilament sutures are more desirable in vascular surgery however, because of their lower infectability, reducing risks of mycotic aneurisms and infection. Continuous sutures are usually used because tension adjusts so that it is evenly distributed around the circumference of the anastomosis and also, they provide a more leak-proof closure than interrupted sutures. Interrupted monofilament nylon or polypropylene sutures can be used for microvascular anastomoses. Silk may be used in anastomosing major vessels in young children where further growth may be expected. Silk loses much of its tensile strength in one year and disappears after two years.⁹²

Prostheses The fixation of vascular prostheses and artificial heart valves requires that the sutures retain their original properties and strength throughout the life of the patient because a prosthesis never becomes completely incorporated into a tissue and constant movement of the suture line occurs. Coated polyester fibers are the sutures of choice, using an interrupted technique. Teflon felt pledgets may be used as a buttress under sutures when tearing of tissue is a possibility. They are most often used in valve replacement procedures to prevent the annulus from tearing when the prosthetic valve is seated and sutures are tied.⁹³

Sutures for the Urinary Tract

As in the biliary tract, closure must be leakproof to prevent leakage of urine into the surrounding tissues. Nonabsorbable sutures can not be used because their presence incites the formation of urinary calculi. Coated polyglactin 910 sutures are ideal because the urinary organs regain wound strength rapidly and are healed within 21 days while polyglactin 910 sutures are absorbed within 28 days. The bladder regains its complete strength within 14 days.⁹⁴

⁹² *Wound Closure Manual* 34.

⁹³ *Wound Closure Manual* 31.

⁹⁴ *Wound Closure Manual* 35.

Sutures for the Female Genital Tract

The female genital tract is a potentially contaminated area, so absorbable sutures are preferred to repair defects. The pelvis and vagina are highly vascular and demand strength during approximation and therefore larger sized sutures are used.⁹⁵

Sutures for Tendons

Tendons heal slowly, so cut ends of tendons must be maintained at close approximation. The suture material used should be inert, strong, and inelastic because tendon ends separate due to muscle pull. Surgical steel is widely used, as well as other synthetic nonabsorbable sutures such as polyester fibers, polypropylene, and nylon. In the presence of infection, more inert materials are preferable.⁹⁶

The suture should be placed so that the surface of the tendon is not interfered with because it is part of the gliding mechanism. The blood supply should be maintained and separation of ends should not occur. The parallel arrangement of tendon fibers in a longitudinal direction makes secure placement of sutures difficult. Figure-eight suturing is sometimes used to prevent suture slippage and gap formation. The Bunnel technique is also often used. The suture is pulled out when its function as a holding structure is not necessary. It is called a pull-out suture and the suture is brought through the skin and fastened over a button.⁹⁷

Sutures for Bone

Bone is usually not sutured. Tendons are sometimes attached to bones with wire sutures. This type of healing is slow and requires permanent material. The periosteum heals rapidly, and if suturing is required, surgical gut or coated polyglactin 910 sutures may be used. If bony structures need to be sutured, such as facial fractures, monofilament surgical steel sutures should be used because immobilization of the fracture line is needed. Interrupted surgical steel sutures are used also for the closure of the sternum after median sternotomy.⁹⁸

⁹⁵ *Wound Closure Manual* 35.

⁹⁶ *Wound Closure Manual* 35.

⁹⁷ *Wound Closure Manual* 35-36.

⁹⁸ *Wound Closure Manual* 36.

Sutures for the Nervous System

The galea and dura are closed using an interrupted technique with surgical silk or braided nylon sutures because they are pliable and knot tying is easier. Braided nylon however, has greater strength and less tissue reaction. Polypropylene suture is used if a continuous technique is used or the area is infected. In peripheral nerve repair, suture gauge must be consistent with nerve size. A microscope should be used for precise suturing, and only the epineurium, the outer sheath, is sutured after the motor and sensory fibers are realigned. Suture strength is not important, but it should not incite inflammatory reactions. Therefore, surgical gut, silk, or cotton should not be used, whereas fine sizes of nylon, polyester, and polypropylene sutures are appropriate.⁹⁹

Sutures for the Eye

The ocular muscles and the conjunctiva and sclera have good blood supplies but the cornea is avascular. Therefore full-thickness corneal wounds heal slowly. In closing corneal wounds such as cataract incisions, sutures should remain in place for about three weeks. Operations for muscle recession on the other hand, which involve suturing muscle to sclera, only require sutures for about one week. Silk used to be used, but it can be irritating in the cornea. Fine sized absorbable sutures are now used. Sometimes, they are absorbed too slowly, such as in muscle recessions, and produce granulomas in the sclera. Sometimes, they are absorbed too quickly in cataract surgery. Polyglactin 910 is useful because of its dependable behavior and it induces less cellular reaction than surgical gut.¹⁰⁰

4.3.4 Summary of Principles for Suture Selection

Adequate suture strength will prevent breakage; secure knots will prevent slipping; but, the nature of the suture material must be understood, as well as the biologic forces in healing wounds and the interaction between the two. The following guidelines may be useful:

1. Sutures are no longer needed when a wound has reached maximal strength. Tissues that heal slowly, such as the skin, fascia, and tendons, should be closed with non-absorbable sutures while tissues that heal rapidly, such as the colon, stomach, and

⁹⁹ *Wound Closure Manual* 36.

¹⁰⁰ *Wound Closure Manual* 37.

bladder, should be closed with absorbable sutures.¹⁰¹

2. Foreign bodies in contaminated tissues may convert contamination into infection. Multifilament sutures should be avoided in these areas, and monofilament absorbable sutures should be used.¹⁰²
3. When cosmetic results are important, close and prolonged apposition of wounds and avoidance of irritants is necessary. The smallest inert monofilament suture materials such as nylon or polypropylene should be used. Skin sutures should be avoided and closure should be subcuticular. Skin closure tape may be used to secure close apposition of skin edges.¹⁰³
4. Foreign bodies in the presence of fluids with high concentrations of crystalloids may induce precipitation and stone formation. In these areas, such as the urinary and biliary tracts, rapidly absorbed sutures should be used.¹⁰⁴
5. Suture size should be the finest size with respect to the material strength of the tissue. Retention sutures should be used if sudden strains on the primary suture line are expected.¹⁰⁵

¹⁰¹ *Wound Closure Manual* 37-38.

¹⁰² *Wound Closure Manual* 38.

¹⁰³ *Wound Closure Manual* 38.

¹⁰⁴ *Wound Closure Manual* 38.

¹⁰⁵ *Wound Closure Manual* 38.

Chapter 5

Mechanical Wound Closure Devices

Suturing has not changed much since it was first used except in suture material quality. However, a new approach to wound closure has emerged and it is changing operative techniques. This new approach saves time in closure, obtains secure and surgically acceptable closures, reduces tissue trauma in certain procedures, and improves cosmetic appearance in other procedures. This approach is the use of mechanical wound closure devices such as ligating clips, surgical staples, and their application instruments.¹

5.1 Ligating Clips

Prior to ligating clips, bleeding from severed vessels was controlled with ligatures and cauteries. In 1908, Dr. Harvaj Cushing used a small U-shaped silver wire held in the jaws of a hemostat to attach to a vessel. Dr. E. G. McKenzie, in 1927, improved Dr. Cushing's original method. He developed clip-forming forceps that cut the silver wire and formed the clip in one action, resulting in uniform clips that could be made quickly. He also used flattened wire instead of rounded wire so that the clip would not twist and fall from the applicator. These clips were widely accepted. Silver however, produced an extensive inflammatory reaction in the surrounding tissue. In 1942, tantalum substituted silver and it produced much less foreign body reaction. In the early 1960s, Dr. Peter Samuels developed a new hemostatic

¹ *Wound Closure Manual: Use and Handling of Sutures, Needles, and Mechanical Wound Closure Devices* (New Jersey: Ethicon, Inc., 1985) 53.

clip that could be applied faster. Ligating clip use expanded to general, cardiovascular, thoracic, urologic, gynecologic, and neurosurgery. In 1980, stainless steel ligating clips were introduced. Absorbable ligating clips were introduced in 1982, and titanium clips in 1984.²

Ligating clips are a rapid and secure method to achieve hemostasis or to ligate arteries, veins, nerves, and other small structures. Ligating clips can be used to permanently occlude major vessels in deep, confined areas. They can also be used in place of free suture ties or stick ties for vessels and structures when control of bleeding must be accomplished quickly. Ligating clips are very useful in deep, difficult to reach areas. Therefore, clips have the advantages of speed, efficiency, and reliability when rapid control of bleeding is necessary.³

5.1.1 Nonabsorbable Ligating Clips

The nonabsorbable materials available are stainless steel, tantalum, and titanium, none of which produce excessive tissue reaction. These clips ligate tubular structures without thermal destruction. Metallic clips are radiopaque, so they are used to mark internal structures for postoperative x-ray identification. Titanium produces the least artifact in CT scans. All three materials are nonmagnetic. Tantalum clips are heavier than stainless steel clips.⁴

Ligating clips are positioned around the tubular structure to be ligated and closed by applying pressure on the applicator handle. The deforming of the clip during closure is shown in Figure 5-1⁵. Applicators are made of stainless steel (Figure 5-2⁶). Ligating clips and applicators come in several sizes, and the applicators are also available in several shapes. The ligation clips come in cartridges (Figure 5-3⁷) and must be loaded into the applicator. Multiple clip applicators are also available, and these are preloaded with 20 or 30 clips. This instrument is disposable, and allows rapid, efficient, ligation. After one clip is placed, the next clip is automatically positioned in the instrument for the next ligation. If the clip has not been placed satisfactorily, it can be removed with a clip remover.⁸

² *Wound Closure Manual* 53.

³ *Wound Closure Manual* 53.

⁴ *Wound Closure Manual* 53.

⁵ Edward Weck Inc., Weck Surgical Division Advertisement for *Hemoclip[®]* Ligation Clips (1990)

⁶ Edward Weck Inc., *Specifying Weck Disposables Made Easy* (1987)

⁷ Edward Weck Inc., *Specifying Weck Disposables Made Easy* (1987)

⁸ *Wound Closure Manual* 53-54.

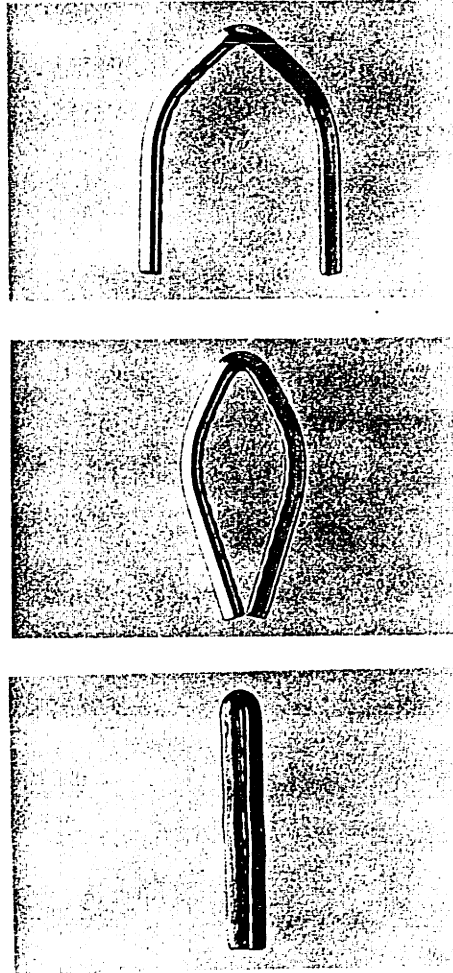


Figure 5-1: The Deforming of a Nonabsorbable Ligation Clip upon Closure

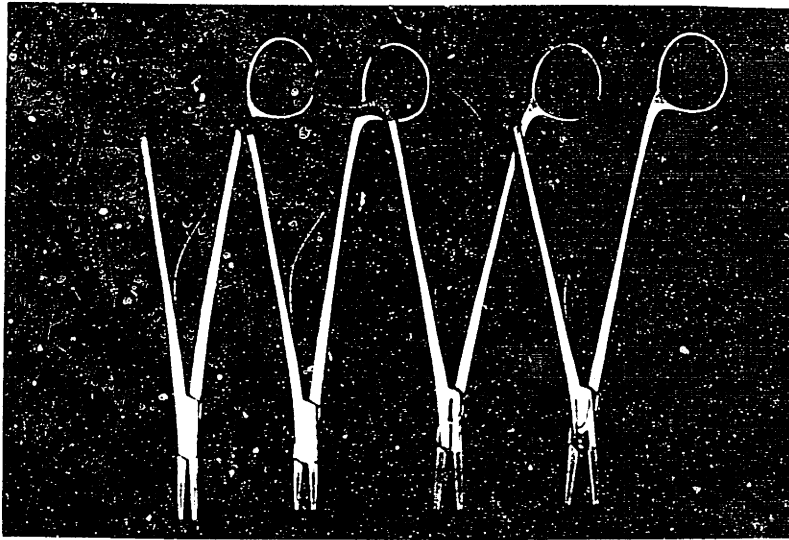


Figure 5-2: Nonabsorbable Ligation Clip Applicators

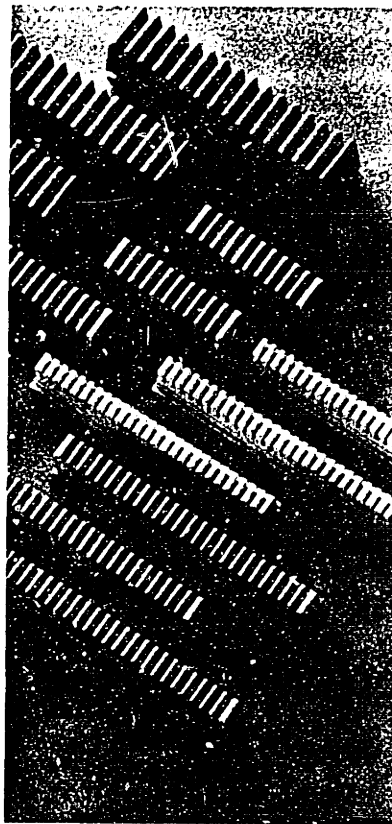


Figure 5-3: Nonabsorbable Ligation Clip Cartridges

5.1.2 Absorbable Ligating Clips

Absorbable ligating clips are molded from the polyester (p-dioxanone), and are sterile, nonantigenic, nonpyrogenic, and produce slight tissue reaction during absorption. These clips are absorbed by hydrolysis by the cleavage of ester linkages. This causes loss of strength and ultimately, the hydrolyzed polymer is removed from the body in urine. Absorption is minimal until the 90th day and is complete within 120 days. These clips hold their strength long enough for a thrombus or clot to occur in the vessel. Absorbable clips are radiotransparent and therefore do not interfere in x-ray or CT scans. Absorbable clips should not be used if prolonged or permanent ligation is desired and the safety of these clips in the vas deferens has not been determined.⁹

Absorbable clips have two legs joined at the proximal ends with a resilient hinge. One leg ends in a deflectable latch which securely fastens the end of the second leg and locks the two legs together (Figure 5-4¹⁰). Absorbable ligation clip applicators are also available in several sizes and they automatically latch the clips. Multiple disposable clip applicators are also available with 20 or 30 absorbable ligation clips.¹¹

5.2 Surgical Staplers

Surgeons have been concerned about the amount of time required and the extent of tissue trauma in certain procedures. In 1908, Professor Hamer Hittl of Hungary developed an instrument to place straight double rows of staples in an alternating manner across the stomach. The staples were B-shaped and made of fine wire. In 1924, Aladar von Petz, also a Hungarian, developed a mechanical device for gastrointestinal anastomosis. Although the instrument was cumbersome, it received worldwide acceptance because it reduced operating time and tissue trauma. It also used silver staples. In 1934, Dr. H. Friedrich of Germany produced a stapling device with replaceable, preloaded staple cartridges, but it was only used for temporary closures. After being stapled, the tissue had to be inverted and sutured. In 1951, a stapling instrument for use in vascular surgery was developed at the Scientific Research Institute for Experimental Surgical Apparatus and Instruments in Moscow. The Russians became leaders in the field of stapling tissue and they licensed patents which

⁹ *Wound Closure Manual* 53-54.

¹⁰ Ethicon, Inc. Advertisement for *Absolok*[™] Extra Absorbable Ligating Clips

¹¹ *Wound Closure Manual* 55.



Figure 5-4: Absorbable Ligation Clips

allowed reusable staplers to become available. In 1967, stapling instruments with disposable staple loading units were introduced in the United States. Each instrument was specific to a certain tissue. In 1978, preassembled disposable stapling instruments were developed.¹²

Basically, a stapler should be designed for certain considerations. The stapler should not obstruct the surgeon's view of the wound edge. It should be narrow enough to gain access to the depths of the wound and recessed anatomical sites. It should be sterile, nonantigenic, lightweight, easy to handle, and should carry sufficient staples.¹³

Stapling allows reduced operation time and reduced tissue trauma because tissue handling is minimized. Stapled skin wounds are more resistant to infection than the least reactive suture, monofilament nylon.¹⁴ However, there are also disadvantages in stapling wounds. Wounds healed with staples are weaker, have a lower modulus of elasticity, and absorb less energy than similar wounds closed with monofilament nylon sutures. Also, wounds approximated with surgical closure tape have a higher resistance to infection than those closed by staples.¹⁵

5.2.1 Skin Staplers

Skin must be brought together in precise approximation with everted edges of the cuticular and subcuticular layers for best cosmetic results. Tissue flattens out and becomes even during healing. The skin must also be aligned close to its original configuration to reduce unnecessary scars. The skin edges are everted and approximated using forceps and applying tension at the ends of the incision. The staples are gently placed across the junction of skin edges uniformly along the incision line. The staples are made of inert 316L stainless steel, and their rectangular design minimizes tissue trauma and staple rotation after placement. Staples should be placed so that there is space between the staple crown and skin surface to minimize tissue compression and crosshatching marks. Staples are flexible because they can be used almost anywhere on the body as long as at least five millimeters exist between the stapled skin and underlying bones, vessels, or organs. The staples come in cartridges and the staplers are sterile, disposable, lightweight, made of high quality medical grade plastic

¹² *Wound Closure Manual* 56.

¹³ Richard F. Edlich, John G. Thacker, George T. Rodeheaver, and Milton T. Edgerton *A Manual for Wound Closure* (Minnesota: Minnesota Mining and Manufacturing Co., 1980) 102.

¹⁴ Robert S. Sparkman, *The Healing of Surgical Wounds* (Pearl River, New York: American Cyanamid Co., 1985) 14.

¹⁵ Edlich 102.

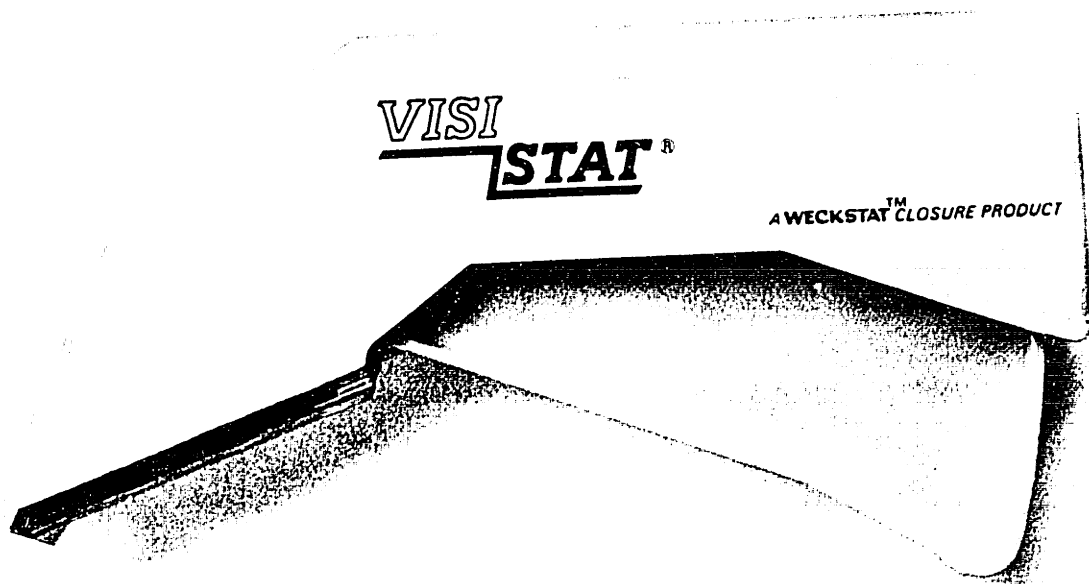


Figure 5-5: Skin Staplers

or stainless steel, and they are available in several configurations. The staples are applied by positioning the instrument over the everted skin edges, squeezing the trigger, releasing the trigger and removing the instrument. Skin staples are removed postoperatively with a skin staple extractor.¹⁶ Various skin staplers are shown in Figure 5-5¹⁷.

5.2.2 Intraluminal Staplers

Disposable intraluminal staplers (Figure 5-6¹⁸) are used for anastomosis of tubular, hollow organs of the alimentary tract. The diseased part of the organ is resected and continuity of the tract is restored by anastomosing the organ. When a hollow organ such as the bowel is resected, the lumen of the two segments is circular. The intraluminal staplers have round staple cartridges that place double rows of staggered staples, resembling the shape of the organ, and allowing its proper functioning. The tissue is inverted. These staplers can

¹⁶ *Wound Closure Manual* 56-58.

¹⁷ Edward Weck Inc., *Specifying Weck Disposables Made Easy* (1987)

¹⁸ *Wound Closure Manual* 60.

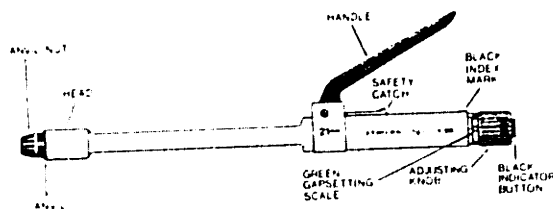


Figure 5-6: Intraluminal Stapler

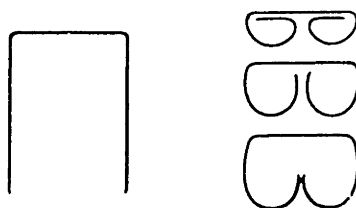


Figure 5-7: Adjustable Staple Height

be used for inverted end-to-end, end-to-side, and side-to-side anastomoses throughout the alimentary tract from the esophagus to the rectum. It is introduced through an enterotomy or gastrotomy site except in low anterior resections, where entry is possible through the dilated anus. The stapler should not be used in ischemic or necrotic tissue.¹⁹

The staplers are made of lightweight alloy and plastic components in several sizes to accommodate different lumen diameters and with adjustable staple height (Figure 5-7²⁰) to accommodate varying tissue thicknesses. The organ diameters must be measured at the two anastomotic sites to determine the stapler size.²¹

Purse-string sutures should be placed in the segments of the organs to be anastomosed prior to inserting the stapler. They should be placed with a through-and-through technique and not an over-and-over (whip stitching) technique. Once the stapler is inserted, the gap between the anvil and head of the stapler is opened exposing the center rod. The purse-string sutures are tied firmly against the center rod and excess tissue is excised. The

¹⁹ *Wound Closure Manual* 58-59.

²⁰ *Wound Closure Manual* 61.

²¹ *Wound Closure Manual* 59.

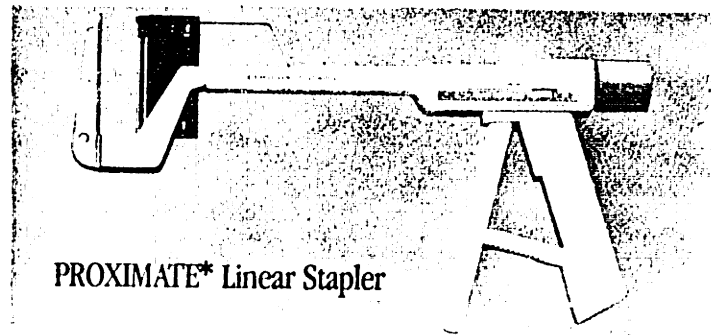


Figure 5-8: Linear Stapler

two tissue segments are properly aligned and the instrument is closed to the proper tissue thickness. Too little pressure will produce leakage while too much might jeopardize blood supply. The stapler is fixed by squeezing on the handle and releases a staggered double row of stainless steel staples. A circular knife in the stapler's head trims the tissue to produce a proper lumen during stapling. The B configuration of staples allows arterioles to carry blood through the stapled region to prevent necrosis and also allows a degree of elasticity comparable to that of sutures. Staples act as horizontal mattress sutures to hold tissue in serosa to serosa in approximation. Tissue is minimally traumatized and the procedure is faster than suturing. The stapler is withdrawn from the organ by opening the gap and rotating the instrument 360° to free it from the staple line. It is disposed and can not be resterilized.²²

5.2.3 Linear Staplers

Linear staplers (Figure 5-8²³) are used throughout the alimentary tract and in thoracic surgery for transection and resection of internal tissues. The stapler delivers a double staggered row of stainless steel staples, and comes in various sizes to accommodate desired staple line lengths and tissue thicknesses.²⁴

The tissue to be transected or resected is positioned in the appropriate length stapler jaws. The anvil and staple compartment are aligned to provide correct staple formation and prevent compressed tissue from slipping in the jaws. The gap is adjusted to be adequate

²² *Wound Closure Manual* 59-61.

²³ Ethicon, Inc. Advertisement for *Proximate*[™] Linear Cutter and *Proximate*[™] Linear Stapler. (1988)

²⁴ *Wound Closure Manual* 61.

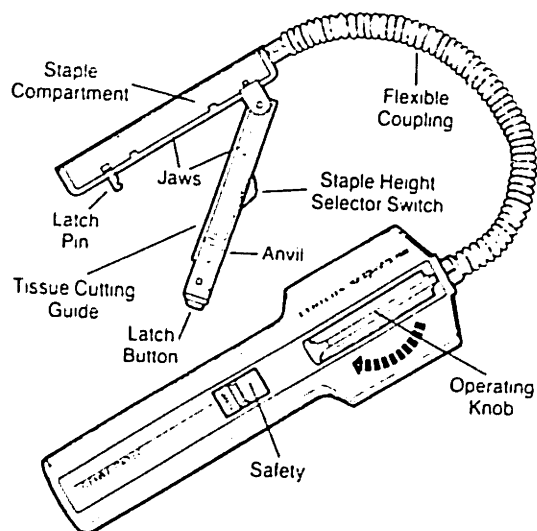


Figure 5-9: Flexible Linear Stapler

for the tissue thickness. The stapler is fired by pulling on the trigger. Before the stapler is removed, the edge of the jaw is used as a cutting guide to transect tissue or excise any tissue protruding through the jaws. This will help cutting at a proper distance from the staple line. The jaws are opened and the stapler is removed and disposed.²⁵

Linear staplers also come with flexible coupling between the handle and the jaws so that versatile placement on internal tissues can be achieved (Figure 5-9²⁶). Two types of flexible linear staplers are available. One type allows transections in the alimentary tract or in thoracic surgery. The other type is designed for gastric applications where there is thicker tissue. Staple height may be adjusted in both, corresponding to different tissue thicknesses. The flexible linear stapler is fired by turning the operating knob. After firing, the jaws are opened by releasing the latch and the anvil is opened to release the tissue. The stapler is disposed after use.²⁷

After the use of any stapler, the staple line must be examined for hemostasis and complete closure.

²⁵ *Wound Closure Manual* G1-G2.

²⁶ *Wound Closure Manual* G1.

²⁷ *Wound Closure Manual* G2.

Chapter 6

Miscellaneous Products and Methods for Wound Closure

6.1 Skin Closure Tapes

Strong, narrow, sterile strips of tape with adhesive backing are used for approximating wound edges and closing wounds.¹ Wounds closed with tape have been shown to have a higher resistance to infection than sutured wounds.² Clinical evidence has also indicated that wounds closed by these tapes develop tensile strength faster than sutured wounds. This may be because stress is uniformly applied to collagen fibers and the tape fibrils that cross the wound help rapid fiber orientation and tensile strength increase.³

The ease and applicability of tape closure depends on the anatomic site. Linear wounds in the skin that are not subject to static or dynamic tensions are easily approximated by tape. The lax skin of the face and abdomen is also well suited for tape closure. Tape closure without sutures is easier in obese patients because there is more force to approximate wound edges than in thin patients and also, the thick edges of adipose tissue tend to evert the skin which helps tape closure. The extremities have taut skin and are subject to dynamic movements, so tape closure must be supplemented with dermal sutures. Skin that is subject to tensions tend to retract and shrink. Dermal sutures stretch the skin to its

¹ *Wound Closure Manual: Use and Handling of Sutures, Needles, and Mechanical Wound Closure Devices* (New Jersey: Ethicon, Inc., 1985) 79.

² Richard F. Edlich, John G. Thacker, George T. Rodeheaver, and Milton T. Edgerton *A Manual for Wound Closure* (Minnesota: Minnesota Mining and Manufacturing Co., 1980) 90.

³ *Wound Closure Manual* 79.

uninjured dimensions prior to taping, and makes tape application easier. Large amounts of secretions from axilla, palms and soles discourage tape adherence. ⁴

When tape is used to close linear wounds that are subject to weak tensions, the tape is first attached to the skin at one wound edge, and the other wound edge is pulled toward the taped edge before the rest of the tape is applied to the skin, as shown in Figure 6-1^{5,6}. Cosmetic results are excellent, and patients do not undergo the discomfort of suture removal and the development of suture puncture scars. In children or women with glabrous skin, tape skin closures leave imperceptible scars on transverse lacerations over the brow, under the chin, or across the malar prominence.⁷

Fine approximation of the wound with adhesive tape at the time of closure is difficult however. Sometimes they are applied to skin over a subcuticular closure in place of skin sutures or sometimes they are used in conjunction with sutures. Sometimes the skin is initially sutured or stapled, and then replaced with tape in four to five days.⁸ The disadvantages of tapes are that they do not bring deeper tissues together and they do not control bleeding from wound edges.⁹

A skin closure tape's performance is judged by its adherence, tensile strength, and porosity. Several types of skin closure tapes are available.

One variety is a surgical tape with a discontinuous layer of polyalkylacrylate, a chemical adhesive, with many micropores throughout its surface. The tape's backing is made of randomly distributed, fine, nonwoven rayon fibers that are reinforced with longitudinal polyester fibers.¹⁰ Its tensile strength is sufficient to maintain wound approximation during healing. The backing maintains its tensile strength even when wet because of its reinforced longitudinal fibers. The tapes porosity allows moisture to spread through its interstices, and skin remains dry and uncondusive to bacterial growth.¹¹

A second variety of adhesive tape is made of woven polypropylene delnet tape coated on one side with a hypoallergenic adhesive mass. The polypropylene construction is unaffected by moisture. The woven polypropylene delnet is very porous for adequate ventilation to

⁴Edlich 90.

⁵*Wound Closure Manual* 80.

⁶Edlich 90-91.

⁷Edlich 92.

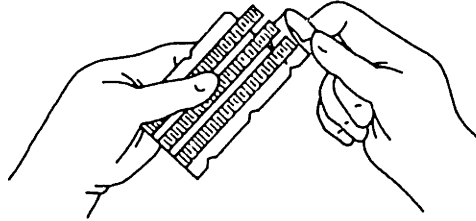
⁸*Wound Closure Manual*, 80.

⁹*Wound Closure Manual* 79.

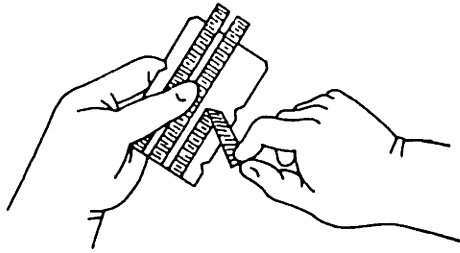
¹⁰Edlich 94.

¹¹Edlich 94.

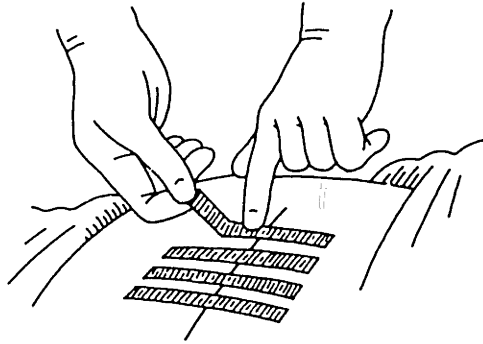
Fig. 49 Skin closure tapes



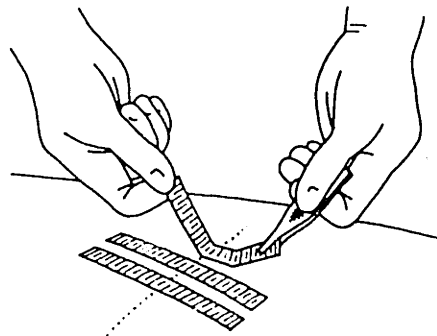
1. Aseptically remove card from sleeve and tear off tab.



2. As needed, peel off skin strips in diagonal direction.



3. Apply additional strips at $\frac{1}{8}$ inch intervals, as needed, to complete wound apposition. Make certain that skin surface is dry before applying each skin strip.



4. When healing is judged to be adequate, skin strips may be removed by peeling off each half of a strip up to the wound margin and then gently lifting the strip away from the wound surface.

Figure 6-1: Application of Skin Closure Tapes

prevent maceration. These tapes are translucent and so the wound edges and progress of healing can be checked.¹²

A third variety of skin closure tape is woven rayon acetate tape that is coated with a hypoallergenic adhesive mass. These tapes can be used by themselves, or to reinforce suture or staple closed skin.¹³

Benzoin tincture, an adhesive adjunct, is sometimes used to enhance the immediate adhesion of tape closure to skin and reduce the risk of tape dislodgement and subsequent wound dehiscence.¹⁴ A tape's adhesive bond to skin increases over time so immediate adhesion is important.¹⁵ Unfortunately, this adjunct impairs the wound's ability to resist infection.¹⁶

6.2 Surgical Meshes

Surgical meshes are used to repair hernias and other fascial or tissue deficiencies that need a reinforcing or bridging material for the desired result. Primary closure of the abdominal wall defects under tension often leads to wound necrosis and infection. If a sheet of mesh is inserted to bridge the defect, the position of the viscera will be maintained until the wound has developed enough granulation tissue to avoid evisceration.¹⁷

Surgical mesh is made from four different materials: stainless steel, polyester fiber, polypropylene, and polyglactin 910. A fascial substitute should be pliable so that it doesn't erode major structures, inert so that great inflammatory responses are avoided, porous so that exudate can be drained and fibroblasts can be ingrown, and resilient so that the integrity of the mesh is obtained.¹⁸

Surgical steel mesh is made of woven stainless steel filaments, is biologically inert, has a high degree of tissue acceptability, and is opaque to x-ray. Its inflexibility produces stiff handling characteristics in comparison to synthetic fiber meshes. It may fragment or cause patient discomfort. These sheets can be cut to the desired shape and size. The mesh should

¹² *Wound Closure Manual* 81.

¹³ *Wound Closure Manual* 81.

¹⁴ Edlich 94.

¹⁵ Edlich 93.

¹⁶ Edlich 94.

¹⁷ *Wound Closure Manual* 81.

¹⁸ *Wound Closure Manual* 81.

be steam sterilized before use.¹⁹

Polyester fiber mesh is made of woven multifilament strands of polyethylene terephthalate. It has excellent strength, durability, surgical adaptability, and maximal porosity for necessary tissue ingrowth. These sheets can be cut to the desired size and shape. This mesh should also be steam sterilized before use.²⁰

Polypropylene mesh is made of knitted filaments of extruded polypropylene (Figure 6-2²¹). It has high burst strength and high tensile strength, is inert and has excellent handling properties.²² Both polyester and polypropylene meshes are knitted by a process that interlinks each fiber junction providing elasticity in both directions. This allows it to adapt to various stresses in the body. They both elicit slight inflammatory responses which only last until a thin fibrous layer of tissue is deposited, incorporating the mesh into adjacent tissue. They are both soft and pliable so normal wound healing is not impaired. The meshes are not absorbed, degraded or weakened. Meshes placed in contaminated wounds might form fistulas.²³

Polyglactin 910 mesh is made from a copolymer of glycolide and lactide. It is used as a buttress to provide support during healing. It is absorbable so it should not be used where extended wound support is required. Support remains significant for at least 14 days and absorption is complete within 21 days.²⁴

Meshes are also available in Dacron felt and Teflon materials.²⁵

All meshes are placed with sutures or staples. Nonabsorbable meshes should be secured with nonabsorbable sutures or staples of the same material. Absorbable meshes can be placed with either absorbable or nonabsorbable sutures or staples.²⁶

¹⁹ *Wound Closure Manual* 81.

²⁰ *Wound Closure Manual* 81.

²¹ *Bard Product Directory* 13.

²² *Bard Vascular Systems Division Product Directory* (Billerica, Massachusetts: Bard Vascular Systems Division, C.R. Bard Inc., 1992) 13.

²³ *Wound Closure Manual* 82.

²⁴ *Wound Closure Manual* 82.

²⁵ *Bard Vascular Systems Division Product Directory* 11.

²⁶ *Wound Closure Manual* 82.

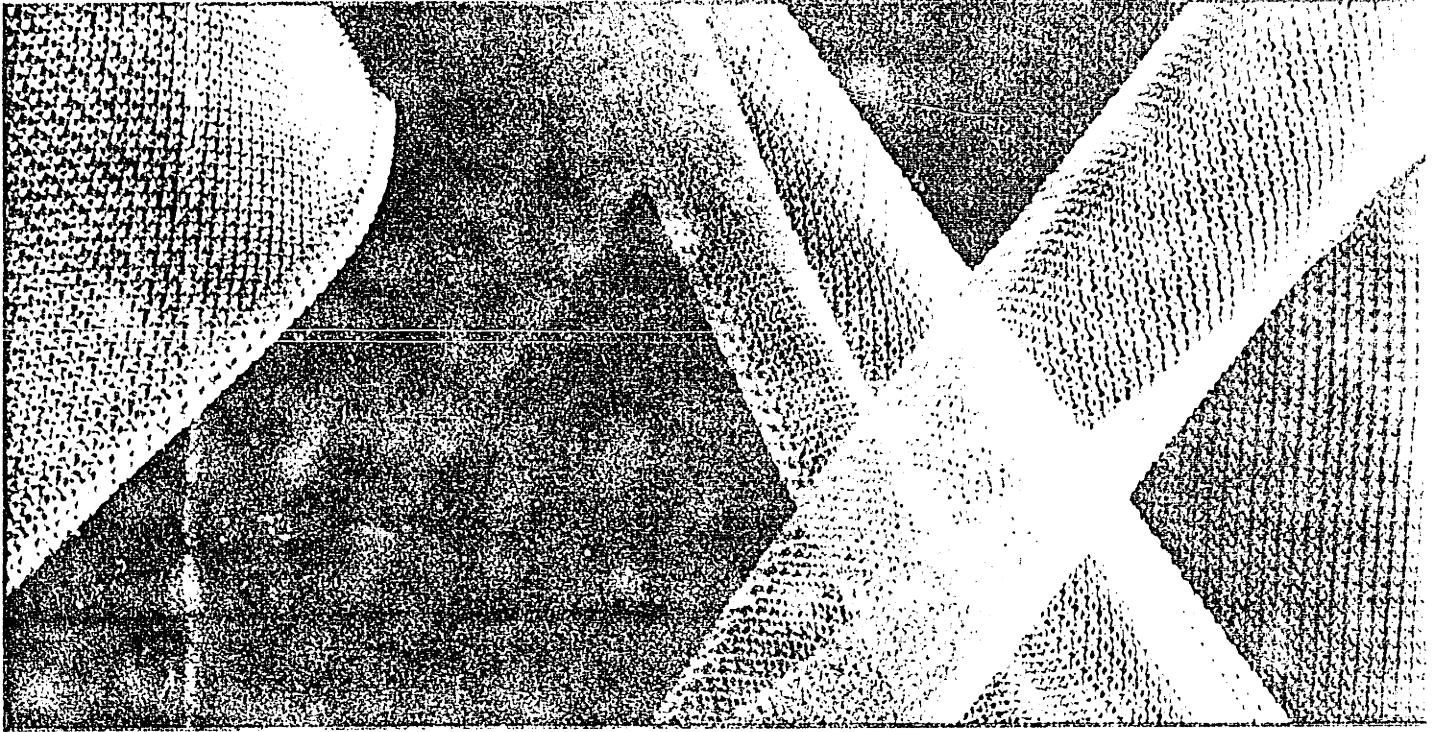


Figure 6.2: Polypropylene Mesh

6.3 Tapes

Tapes can also be used for ligation, repair, and support in some procedures. The tape is made of polyester fiber and comes in strips with or without needles.²⁷ Tapes are used when incompetence of the cervix is encountered. This condition is characterized by habitual, premature, spontaneous abortions of the fetus. A ligature is placed around the cervix like a collar, drawn tight, and tied or sutured closed.²⁸ Tapes are also used to repair and support the rotator cuff in the shoulder. Tapes come attached to heavy needles specially designed for orthopedic surgery.²⁹

Umbilical tape is made of woven cotton that is used as a ligature in pediatric and cardiovascular procedures to suspend small structures and vessels and also to tie off the umbilical cord of a newborn infant. Umbilical tape easily absorbs blood and it is also available with radiopaque threads for identification by x ray.³⁰

²⁷ R. S. Standish, *Medical Texts*.

²⁸ R. S. Standish, *Medical Texts*.

²⁹ R. S. Standish, *Medical Texts*.

³⁰ R. S. Standish, *Medical Texts*.

6.4 Hemostatic Agents

Many varieties of hemostats are available in an attempt to achieve hemostasis. Topical hemostats are common. One variety of topical hemostat is a biocompatible agent of collagen origin which has been treated to produce a positive charge. This is done by modifying the collagen hemostatic sponge so that it contains calcium chloride. This sponge dissolves while carrying out its hemostatic effect. When it is in contact with blood, it activates the coagulation mechanism. It is used when hemostasis is required along suture lines in diffusely bleeding sites, incisions, dissections, and around arterial and vessel anastomoses. It is used as an adjunct to conventional closure techniques.³¹

A second hemostat is called bone wax. It is a mixture of beeswax and isopropyl palmitate which softens the wax. It achieves local hemostasis of bone by acting as a mechanical barrier. It does not act biochemically. It should be used sparingly because it may inhibit osteogenesis. It should not be used where rapid osseous regeneration and fusion are desired. Mild inflammatory reactions have been evidenced in adjacent tissues. Bone wax may also impair fighting bacteria.³²

6.5 Looped Sutures

Looped sutures can be used for continuous closure of the fascia in the abdominal wall. It is a simple and reliable technique to close the fascia, and this form of looped suture is monofilament and made of nylon.³³ Other looped sutures are made of chromic catgut and are used for the precise placement of ligatures.³⁴

6.6 Lasers

Lasers are used for cutting, coagulation, or vaporization. As far as wound closure is concerned, we are only concerned with coagulation. Coagulation occurs when the tissue is heated to 60°C. A laser system needs an excitation source that can be electrical, chemical,

³¹Edward Weck Inc. Weck Surgical Division Advertisement for *Superstat^R* (Modified Collagen Hemostat) 1990

³²*Wound Closure Manual* 78.

³³*Wound Closure Manual* 79.

³⁴J. Barry McKernan and Henry L. Laws. *Laparoscopy and the General Surgeon* 10.

flash lamps or another laser. The active medium may be gas, liquid or solid. Surgeons can use either an argon, KTP, ND:TAG, or carbon dioxide laser.³⁵

6.7 Electrocautery

Electrocautery units can be used for cutting or coagulation, but are mainly used for coagulation during laparoscopy. Electrical generators power electrocautery devices and some of the generators are coupled with irrigation pumps to allow simultaneous irrigation with the probe. Cautery probes may have permanent or disposable tips. Tips are available at various angles for optimal placement during cautery. Specialized probes combine cautery with a biopsy device to collect polyps or other tissue specimens for later histological analysis. An alternative to electrocautery is the use of a heater probe. Heater probes generate heat at the tip for coagulation.³⁶

6.8 Heat Lamp Therapy

Heat lamp therapy warms the wound, increases the rate of epithelialization and increases microcirculation, enhancing the healing of the the wound. The wound must be shallow, clean, and show evidence of epithelialization. The lamp must be a 60 to 100 watt bulb, and should be no closer to the patient than two to three feet. Treatments should not last more than 20 minutes. Patients who are combative, disoriented, and have a decreased sensory perception should not be candidates. Heat lamps should not be used on post-myocutaneous flap sites.³⁷

6.9 Wound Irrigation Therapy

Wounds are irrigated to remove non-viable debris, reduce the bacterial count, and promote wound healing. Irrigation can be done under both low and high pressure. Low pressure irrigation is performed with a bulb syringe, a gravity drip, or a surgical drain. High pressure

³⁵Sandhya Vasan. *Endoscopic Surgery: An Assessment of Laparoscopic and Arthroscopic Techniques and Instrumentation* (Massachusetts:Massachusetts Institute of Technology Bachelor's Thesis, May 1992) 49.

³⁶Vasan 52-53

³⁷Diane Krasner. *Chronic Wound Care* (King of Prussia, Pennsylvania: Health Management Publications, Inc., 1990) 309-310.

irrigation is performed with a jet lavage or syringe and needle with maximum force. Low pressure irrigation is somewhat ineffective in reducing high bacterial counts and removing wound debris. Its advantage is that it does not traumatize tissue as much as high pressure irrigation. High pressure irrigation produces more tissue trauma and suppuration and should not be used on highly contaminated wounds. The dental irrigating device can also be used for high pressure irrigation on pressure ulcers, for debridement and for stimulation of local circulation.³⁸ Irrigation fluid can also contain a dilute antibiotic such as neomycin or povidone-iodine so the process combines debridement with topical antibiotic therapy.³⁹

Wound irrigation can also be performed using a catheter input and either suction catheter drainage or simple evaporation of the solution from a bulky absorbant dressing. Suction removal is used in wounds that will be closed, and evaporation is used when closure is not possible.⁴⁰

6.10 Topical Oxygen Therapy

Topical oxygen is delivered to the wound by a small chamber secured to the body surface or by a sleeve that fits over an extremity and delivers oxygen under a set pressure. The small chambers are made of pliable material that can mold to the body surface. Topical oxygen therapy is thought to inhibit bacterial growth, stimulate white cell production, and increase the rate of wound healing by enhancing cellular reproduction, increasing collagen synthesis rate, and increasing epithelialization rate. Oxygen is forced only into the superficial layers of the wound, so the wound must depend on the body's blood supply for healing.⁴¹

6.11 Topical Antibiotic Therapy

Topical antibiotics are widely used in chronic wounds. Some researchers believe that topical antibiotics are ineffective, especially in the presence of necrotic tissue. Antibiotics may even promote the growth of resistant organisms. Prolonged use of antibiotics can produce allergic dermatitis. Neosporin ointment's ingredient, zinc bacitracin actually enhances epidermal healing. Topical antibiotics should be chosen carefully. An ideal antibiotic is one

³⁸Krasner 310.

³⁹John M. Finley. *Practical Wound Management* (Chicago: Year Book Medical Publishers, Inc., 1981) 9.

⁴⁰Finley 9.

⁴¹Krasner 311.

that reduces the bacterial count of the wound, is painless, and does not impede normal wound healing. Antibiotic therapy should be used for a limited period of time and the wound should regularly be reassessed.⁴²

6.12 Aloe

Aloe comes from the aloe vera plant. The gel of this plant is extracted and used in wound care products. Studies show that the components of aloe vera can increase dermal profuaion, decrease inflammation, produce an anaesthetic reaction, and kill bacteria.⁴³

6.13 Honey/Sugar

Sugar is believed to enhance wound healing by debriding the wound and destroying bacteria through its osmotic reaction. High concentrations of sugar alter the wound pH, which produces a toxic environment for invading microorganisms. The hypertonicity of sugar releaves surrounding edema so that serum and nutrients can enter the tissues. Sugar may even ferment within the wound, producing alcohols that can act as an antiseptic. Sugars in wounds also lower the water activity level so that microorganisms can't grow. Studies have shown an increase in granulation tissue growth and rapid wound debridement and closure when sugars were used to treat wounds.⁴⁴

6.14 Sugar and Povidone-Iodine Preparations

The beneficial aspects of sugar are given above. Povidone-iodine acts as a germicide and antifungal agent. The combination is nonallergenic and mixes well. Studies have shown dramatic improvements in wounds treated with this mixture and an increase in healing rate. However, povidone-iodine has been shown to be cytotoxic, toxic to fibrobalsts, and impeditory to wound healing.⁴⁵

⁴²Krasner 312-313.

⁴³Krasner 313.

⁴⁴Krasner 314.

⁴⁵Krasner 314-315.

Chapter 7

New and Future Technologies, An Overview

In the past two decades, wound care has changed dramatically, but mainly due to the expansion of the market. The most significant changes in wound care are due to advances in technology and the understanding of mechanisms that regulate wound healing. These factors have combined the scientific principles of organic and polymer chemistry, molecular and cell biology, and biochemistry to produce innovative, effective, and interactive wound care products.¹

The philosophy behind the development of interactive wound management products was based on the idea that if a wound's microenvironment was optimal for healing, then it would heal spontaneously. However the rate of healing was believed to be a biologic maximum and could not be accelerated beyond the capabilities of the tissues.²

However through experiments, scientists and researchers have learned that it is possible to stimulate the normal activity involved in tissue repair by topical activation. Products that are capable of producing a localized systemic intervention to aid the healing process are classified as active products. Active products are the next stage in the evolution of wound management products from early passive products to the current interactive products and finally to future active materials.³

¹Diane Krasner, *Chronic Wound Care* (King of Prussia, Pennsylvania: Health Management Publications, Inc., 1990) 125.

²Krasner 39.

³Krasner 39.

Researchers have noticed that wound healing in the fetus is done without scar formation, and they have been studying this in efforts to duplicate this phenomenon of scarless healing in adults. Fetal wound healing occurs without a classic acute inflammatory response without early infiltration by polymorphonuclear cells. Instead there is an infiltrate of small mononuclear cells and deposition of a matrix that is rich in proteoglycan and a decrease in fibroblasts and collagen. Studies have shown that collagen is present in fetal wounds when a chemoattractant for neutrophils is added. Polymorphonuclear cells appear in the wounds and initiate a sequence of events leading to fibroblast attraction and collagen formation as adult wounds. Studies have also shown that fetal fibroblasts synthesize collagen more proficiently than adult fibroblasts, but they only synthesize minimal, essential amounts of collagen instead of producing excess, distorted arrays of scar collagen.⁴ It is possible that regeneration and scarring follow similar mechanisms but that distinct growth factors are utilized, and if the process is understood, scarless regeneration might be possible in adults.

Another method of wound management that is currently being researched is the prefabrication of custom-made flaps on arteriovenous bundles. This technique is on the brink of clinical application. A dominant blood supply is created in tissues lacking one by relocating and arteriovenous bundle and allowing neovascularization to occur in these tissues. These tissues can then be separated from their original source and transferred as a free flap on the new axial vessels. Custom shaped bone and cartilage can also be designed and transplanted. Fibroblast growth factor has an angiogenic effect that increases neovascularization and improves the prefabricated flap survival.⁵

The use of cultured epidermal allografts in the treatment of chronic wounds is also a plausible future treatment method. Keratinocytes synthesize and secrete several growth factors, including Interleukin-1 (IL-1), a cytokine that stimulates the secretion of platelet derived growth factor (PDGF) and enhances reepithelialization of partial thickness skin wounds. Allografts interact with resident wound cells to deliver the appropriate signals for migration, proliferation, and protein synthesis, and this provides the required factors, at the optimal dose and duration, in the ideal wound environment to facilitate closure and naturally end the healing process.⁶

⁴Michael C. Stanlecker. "Plastic Surgery." *The Journal of the American Medical Association* 19 May 1989: 2878.

⁵Stanlecker 2878.

⁶Krasner 427.

Matrix replacements are also plausible. The extracellular matrix (ECM) is a dynamic structure that can modulate tissue development and regulate tissue repair. Studies have shown that wounds created by freezing (cell death without matrix destruction) heal with less contraction than wounds generated by heat (cell death with matrix destruction). It has been shown that collagen/glycosaminoglycan (GAG) combinations modulate inflammation, fibroplasia, and angiogenesis in implantable wound sponges. Matrix replacements may also be used as biologic delivery systems, releasing effector molecules by pulsed, sustained, or controlled release, effecting repair. The effector molecule may even be stabilized by the ECM. The matrix may also be seeded with autologous cultured keratinocytes, forming a biocompatible artificial skin.⁷

Large amounts of research and development is occurring in the field of growth factors. Growth factors for wound healing are a class of therapeutic proteins that are expected to accelerate the healing of various wounds. These substances are currently in early and mid-stage clinical trials to test their efficacy. If they are found to promote the healing process, it is likely that they will be widely used. Their combination with a dressing, if an effective delivery mechanism is provided, will result in a product that clearly improves wound healing. Products will probably be developed between 1995 and 2000.⁸

Proper treatment regimen, optimum dose, optimal delivery system, ideal dressing, stability of the factor in various wound fluids, effect of negative feedback on reparative cells, appropriate supportive therapy, and the relationship between the factor and a specific wound therapy must be determined prior to the clinical use of growth factors.⁹

The most probable delivery systems for growth factors will be the use of polymeric gels such as hydrogels and also collagen matrices. Polymers however must become more biocompatible and biodegradable, erosion must become more predictable, and polymers might even become more customized to particular growth factors and applications. Growth factors will also be applied topically. Growth factors must also become more stable. The delivery systems must also easily administer the factors through sustained release.¹⁰

The development of epidermal growth factor (EGF) is more advanced than any other growth factor. Soft tissue wound healing may be enhanced by epidermal growth factor, fi-

⁷Krasner 427-429.

⁸Krasner 460.

⁹Krasner 429.

¹⁰Krasner 447.

broblast growth factor, and platelet derived growth factor among others. Hard tissue wound healing may be enhanced by transforming growth factor alpha, transforming growth factor beta, fibroblast growth factor and others. Metabolic disorders and osteoporosis may be treated with insulin-derived growth factor. Neurodegenerative diseases such as Alzheimer's Disease, Parkinson's Disease, and amyotrophic lateral sclerosis (Lou Gehrig's Disease) may be treated with nerve growth factor.¹¹

Among suturing and mechanical devices, improvements in design will probably be seen, with easier application and handling. Possibly, an automated suturing device may be developed and put on the market. Current suturing techniques are tedious, laborious, and time consuming. It is equipment limited especially in hard to access areas. Faster knotting techniques or knot substitutes may be employed. An automated suturing device should be as quick and easy to use as the stapler, or it will not be able to compete with staplers. The device should be able to grasp the tissue, place the suture, tie the knot and cut the suture in one operation.

Staplers and ligation clip devices will see improvements in design. Possibly, if growth factors are shown to be highly effective, we may find sutures, staples, and ligation clips laced with growth factors to enhance wound healing. The same can be said about skin closure tapes.

The development of a surgical microstapler is underway, which does not require the use of a staple bending anvil that must be retracted after the staple has been implanted. This type of device may be used for the stapling of very delicate tissue incisions such as those involved in ophthalmic operations, neurosurgery, or plastic surgery. Variations in design of a microstapler have been developed such as a system used for curved paths such as the eye, and have been patented. William D. Richards and Ernesto E. Blanco are inventors of three such patented devices.¹²¹³¹⁴ It is likely that these designs will be improved and placed on the market. Figure 7-1¹⁵ shows the design of one such stapler, Figure 7-2¹⁶ shows

¹¹Krasner 447.

¹²William D. Richards, Ernesto E. Blanco, Richard A. Clark, and John C. Meade. *United States Patent Number 4762260* August 9, 1988

¹³William D. Richards and Ernesto Blanco. *United States Patent Number 4895289* January 23, 1990

¹⁴William D. Richards, John C. Meade, and Ernesto E. Blanco. *United States Patent Number 4969591* November 13, 1990

¹⁵US Patent Number 4762260

¹⁶Photograph belonging to Professor Ernesto Blanco, M.I.T.

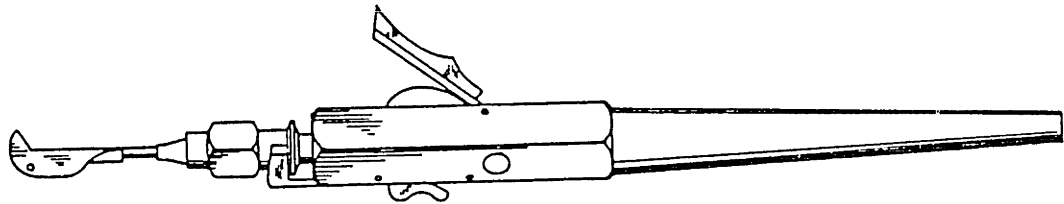


Figure 7-1: Design of an Ophthalmic Stapler

the size of the cartridges of microstaplers and Figure 7-3¹⁷ shows an eye with both sutures and microstaples for comparison.

The next decade will see a wide array of new and improved wound management and closure products being developed and marketed. The future medical practitioners will have many options in the treatment of wounds. This will enable treatment of wounds on a highly specific basis, with the choice of closure and dressing materials based on the particular characteristics of the wounds.

¹⁷Photograph belonging to Professor Ernesto Blanco, M.I.T.

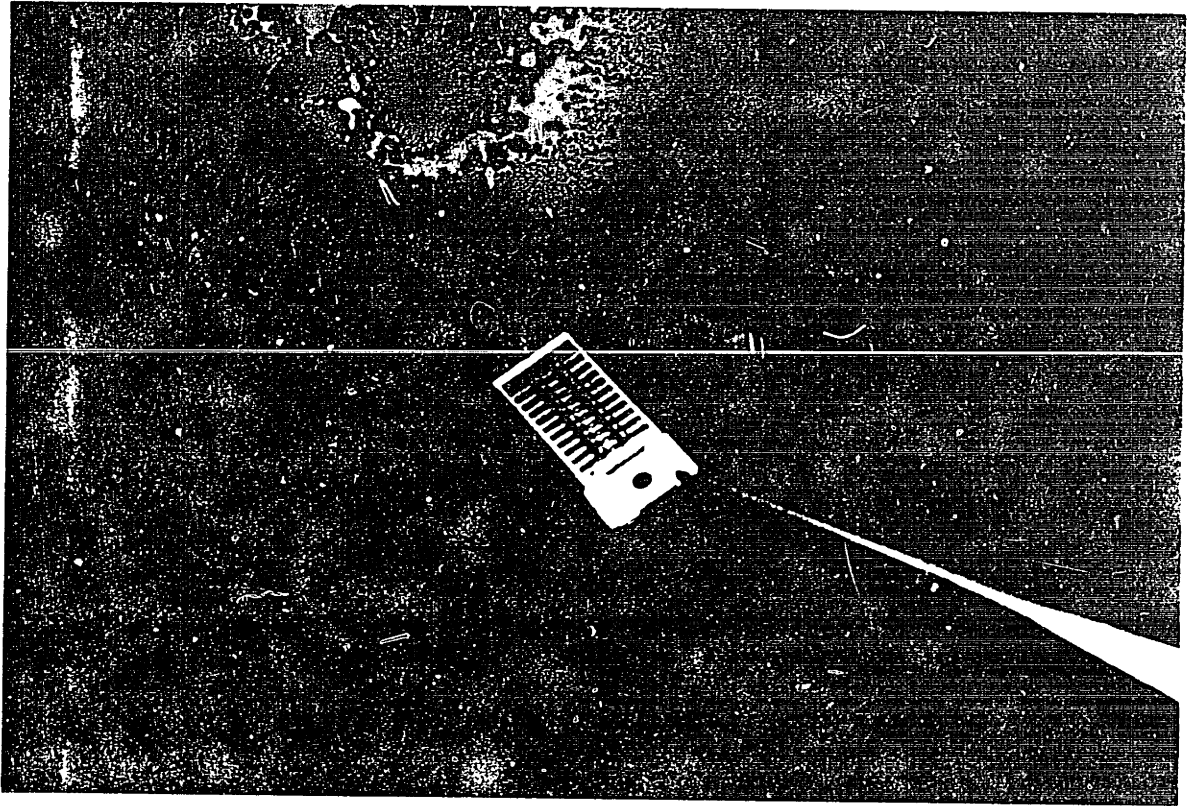


Figure 7-2: A Cartridge of Microstaples

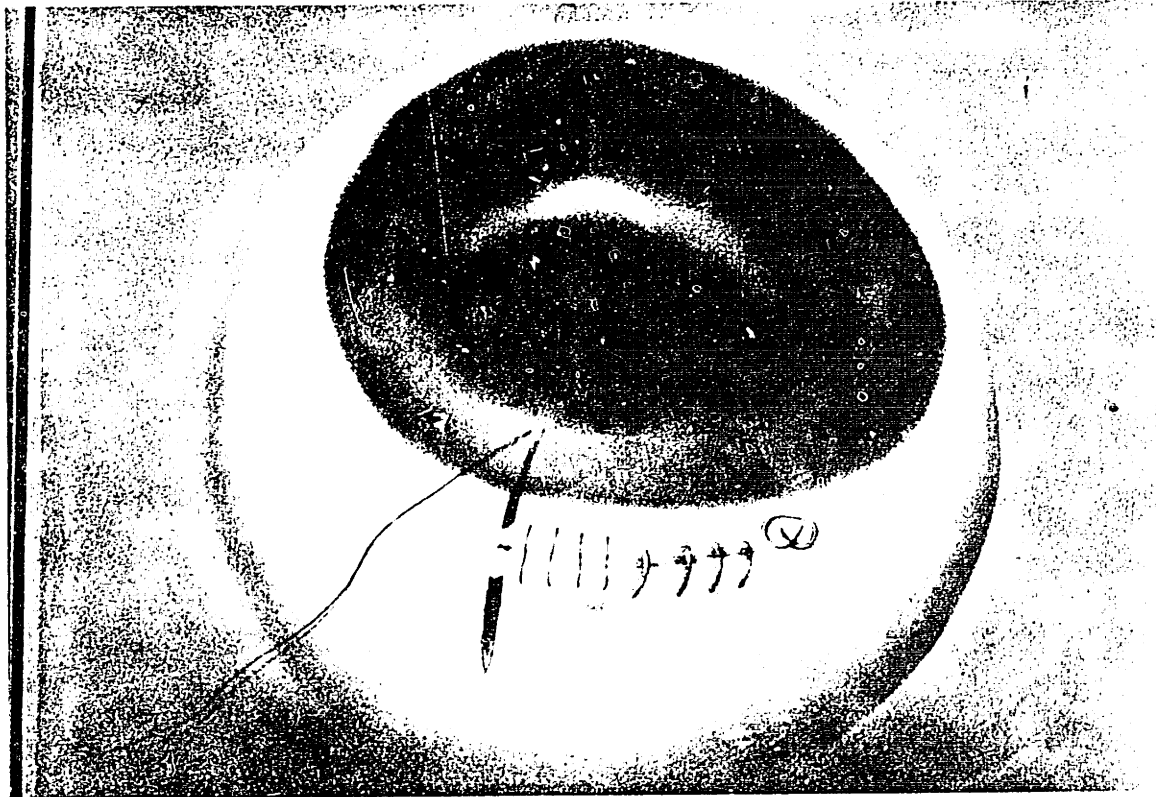


Figure 7-3: A Comparison of Sutures and Microstaples in the Eye

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