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Surgical Knot Tying Manual

Third Edition

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Richard F. Edlich, M.D., Ph.D.

Distinguished Professor of Plastic Surgery,
Biomedical Engineering and Emergency Medicine

Founder of DeCamp Burn and Wound Healing Center
University of Virginia Health System

Director of Trauma Prevention, Education and Research
Trauma Specialists, LLP, Legacy Emanuel Hospital
Portland, Oregon

William B. Long III, M.D.

President and Medical Director, Trauma Specialists, LLP,
Legacy Emanuel Hospital
Portland, OR

forward

If this manual heightens only perceptibly students, nurses, nurse practitioners, physician assistants, surgical residents and surgeon's interest in the biology of wound closure and infection, the long years occupied in my search for improved methods of wound management would more than fulfill my expectations. However, another important purpose of this manual is to honor my colleagues, who collaborated in our clinical and experimental research investigations. It is a duteous pleasure to acknowledge the great help that I have received from Dr. George T. Rodeheaver, Distinguished Research Professor of Plastic Surgery, University of Virginia Health System and Dr. John G. Thacker, Vice-Chairman of the Department of Mechanical and Aerospace Engineering, University of Virginia, who have made numerous scientific contributions to my studies of wound closure. Dr. Thacker and Dr. Rodeheaver are excellent teachers who provide the insight and imagination that solve the most challenging problems. It is also important to note that studies have been undertaken with gifted surgeons in Trauma Specialist, LLP who have developed the only verified Level I Trauma Center in the Pacific Northwest. Dr. William B. Long III, President and Medical Director of Trauma Specialists, LLP, of Legacy Emanuel Hospital has played an instrumental role in evaluating the performance of surgical products for trauma care that are used throughout the world.

Richard F. Edlich M.D., Ph.D.

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I. individualized self instruction

The root origin of the word education is educare or to anglicize it, edu-care. The meaning of education, therefore, is to care for, to nourish, to cause to grow. This being their ultimate responsibility, teachers of surgery should be the most responsive component of the instruction system. Numerous other pressing clinical and administrative commitments, however, often limit interactions with the medical students, nurses, nurse practitioners physician assistants, surgical residents and surgeons. Consequently, learning difficulties may not be identified.

This manual was designed to be a self-instructional teaching aid for the medical student, resident, and surgeon providing an individualized environment of learning. For convenience, each page of this manual has wide margins to accommodate personal thoughts and further clarification. This manual is bound in a ring binder so that it lies flat, a prerequisite for any knot tying manual. The reader should take as little or as much time as needed to digest the information and to develop the illustrated psychomotor skills. At the end of this instruction, you should feel considerably more comfortable in understanding the science of tying surgical knots. More importantly it is our hope that this manual will inspire, motivate, and encourage creativity and self-direction in your study of the biology of wound repair and infection.

This Knot Tying Manual is available online at www.covidien.com/syneture.

II. introduction

Through the ages, the tying of knots has played an important role in the life of man.¹ Most of the ancient civilized nations, as well as savage tribes, were accomplished rope makers. Because rope could have served few useful purposes unless it could be attached to objects by knots, man's conception of the rope and the knot must have occurred concomitantly. Knotted ropes played many important roles in the ancient world, being used in building bridges and in rigging ships.

Because rope and knots have been two of man's most useful tools since the dawn of history, it is not surprising that they also have symbolic and even magical connotations. It was the custom of Roman brides to wear a girdle tied with a square (reef) knot, which their husbands untied on their marriage night, as an omen of prolific offspring. Moreover, it was believed that wounds healed more rapidly when the bandages which bound them were tied with a square (reef) knot.

This mythology of knots may have contributed to some surgeon's perception of surgical knots more as an art form, than as a science. For those artisans, the use of methods and materials for suturing is usually a matter of habit, guesswork, or tradition.² This approach to suturing has contributed to a growing concern that the knot construction employed by many surgeons is not optimal and that they

use faulty technique in tying knots, which is the weakest link in a tied surgical suture. When the recommended configuration of a knot, ascertained by mechanical performance tests was compared to those used by board-certified general surgeons, only 25% of the surgeons correctly used the appropriate knot construction.³ Of the 25 gynecologists, mostly department heads, who were polled about their knot tying technique, most were convinced they they made square knots, even though their knot tying technique resulted in slipknots that became untied.⁴ When a knotted suture fails to perform its functions, the consequences may be disastrous. Massive bleeding may occur when the suture loop surrounding a vessel becomes untied or breaks. Wound dehiscence or incisional hernia may follow knot disruption.

As with any master surgeon, he/she must understand the tools of his/her profession. The linkage between a surgeon and surgical equipment is a closed kinematic chain in which the surgeon's power is converted into finely coordinated movements that result in wound closure with the least possible scar and without infection. The ultimate goal of this linkage the perfection of the surgical discipline. This manual has been written for medical students, nurses, nurse practitioners physician assistants, surgical residents and surgeons who view themselves as scientists cultivating and practicing the science of surgery.

III. scientific basis for the selection of surgical sutures

There are several different suture materials and needles that provide an accurate and secure approximation of the wound edges. Ideally, the choice of the suture material should be based on the biological interaction of the materials employed, the tissue configuration, and the biomechanical properties of the wound. The tissue should be held in apposition until the tensile strength of the wound is sufficient to withstand stress. A common theme of the many reportable investigations is that all biomaterials placed within the tissue damage the host defenses and invite infection. Because surgical needles have a proven role in spreading deadly blood borne viral infection, the surgeon must select surgical gloves that reduce the risk of accidental injuries during surgery.⁵

Important considerations in wound closure are the type of suture, the tying technique, and the configuration of the suture loops. Selection of a surgical suture material is based on its biologic interaction with the wound and its mechanical performance in vivo and in vitro. Measurements of the in vivo degradation of sutures separate them into two general classes.⁶ Sutures that undergo rapid degradation in tissues, losing their tensile strength within 60 days, are considered absorbable sutures. Those that maintain their tensile strength for longer than

60 days are nonabsorbable sutures. This terminology is somewhat misleading because even some nonabsorbable sutures (i.e., silk, cotton and nylon) lose some tensile strength during this 60-day interval. Postlethwait⁷ measured the tensile strength of implanted nonabsorbable sutures during a period of two years. Silk lost approximately 50% of its tensile strength in one year and had no strength at the end of two years. Cotton lost 50% of its strength in six months, but still had 30-40% of its original strength at the end of two years. Nylon lost approximately 25% of its original strength throughout the two-year observation period.

1. Nonabsorbable surgical sutures

The nonabsorbable sutures of Covidien (formerly Tyco Healthcare, Norwalk, CT) can be classified according to their origin. Nonabsorbable sutures made from natural fibers are silk sutures. Sofsilk™ silk sutures are nonabsorbable, sterile, non-mutagenic surgical sutures composed of natural proteinaceous silk fibers called fibroin. This protein is derived from the domesticated silkworm species *Bombyx mori* of the family bombycidae. The silk fibers are treated to remove the naturally-occurring sericin gum and braided sutures are available coated uniformly with a special wax mixture

III. scientific basis for the selection of surgical sutures (cont'd)

or silicone to reduce capillarity and to increase surface lubricity which enhances handling characteristics, ease of passage through tissue, and knot run-down properties. Sofsilks™ sutures are available colored black with Logwood extract.

Metallic Steel sutures are derived from monofilament stainless steel. Modern chemistry has developed a variety of synthetic fibers from polyamides (nylon), polyesters (Dacron™), polyolefins (polyethylene, polypropylene), polytetrafluoroethylene, to polybutester.

Polypropylene is a linear hydrocarbon polymer that consists of a strand of polypropylene, a synthetic linear polyolefin. All polypropylenes begin with a base resin and then go through the following steps: extrusion, drawing, relaxation, and annealing. Each step in the process will influence the ultimate biomechanical performance of the suture. Biomechanical studies demonstrate that the manufacturing process (i.e., annealing, relaxation) can dramatically influence the surface characteristics without altering its strength. Changes in the surface characteristics can facilitate knot construction of the suture. Polypropylene sutures (Surgipro™) that have a low coefficient of friction will facilitate knot rundown and suture passage through the tissue. A new polypropylene suture

(Surgipro™ II) has been developed that has increased resistance to fraying during knot rundown. Polypropylene sutures are extremely inert in tissue and have been found to retain tensile strength in tissues for a period as long as two years. Polypropylene sutures are widely used in plastic, cardiovascular, general, and orthopedic surgery. They exhibit a lower drag coefficient in tissue than nylon sutures, making them ideal for use in continuous dermal and percutaneous suture closure.

Monosof™ and Dermalon™ are monofilament sutures composed of the long-chain polyamide polymers Nylon 6 and Nylon 6.6. They have a high tensile strength and low tissue reactivity. The pliability characteristics of these sutures permit good handling. Because nylon sutures are more pliable and easier to handle than polypropylene sutures, they are favored for the construction of interrupted percutaneous suture closures. However, polypropylene sutures encounter lower drag forces in tissue than nylon sutures, accounting for their frequent use in continuous dermal and percutaneous suture closure. Nylon sutures are also available in a braided construction. Only nylon sutures are available both as monofilament and multifilament sutures (Surgilon™). These braided nylon sutures are relatively inert

III. scientific basis for the selection of surgical sutures (cont'd)

in tissue and possess the same handling and knot construction characteristics as the natural fiber, silk sutures (Sofsilks™).

Polyester sutures (Surgidac™, TiCron™) are comprised of fibers of polyethylene terephthalate, a synthetic linear polyester derived from the reaction of a glycol and a dibasic acid. Polyester sutures were the first synthetic braided suture material shown to last indefinitely in tissues. Their acceptance in surgery was initially limited because the suture had a high coefficient of friction that interfered with passage through tissue and with the construction of a knot. When the sutures were coated with a lubricant, polyester sutures gained wide acceptance in surgery. This coating markedly reduced the suture's coefficient of friction, thereby facilitating knot construction and passage through tissue. The TiCron™ polyester sutures are coated with silicone, while the surface lubricant for Surgidac™ is polybutylene adipate. Because some surgeons prefer to tie sutures with a high coefficient of friction, the Surgidac™ sutures are also available without a surface coating.

The polybutester suture (Novafil™) is a block copolymer that contains butylene terephthalate (84%) and polytetramethylene ether glycol terephthalate (16%).

Polybutester suture has unique performance characteristics that may be advantageous for wound closure.⁸ This monofilament synthetic nonabsorbable suture exhibits distinct differences in elongation compared with other sutures. With the polybutester suture, low forces yield significantly greater elongation than that of the other sutures. In addition, its elasticity is superior to that of other sutures, allowing the suture to return to its original length once the load is removed. In a study by Trimbos et al.⁹ they compared the cosmetic outcome of lower midline laparotomy scars using either nylon or polybutester suture for skin closure. A randomized clinical trial compared polybutester skin suture with that of nylon for lower midline laparotomy wounds in 50 women undergoing gynecologic surgery. Scar hypertrophy, scar width, scar color, the presence of cross-hatching marks, and a total score was assessed in all patients at 18 months following surgery and compared by nonparametric statistical tests. The wounds closed with polybutester suture were significantly less hypertrophic than those closed with nylon. Regardless of the suture material used, the lower part of the laparotomy scar showed an inferior cosmetic result compared with the upper part underneath the umbilicus for scar hypertrophy, scar width, and the total scar score. The surgeons concluded that polybutester skin suture diminished the risk of

III. scientific basis for the selection of surgical sutures (cont'd)

hypertrophic scar formation because of its special properties allowing it to adapt to changing tensions in the wound. Increased closure tension of the skin in the midline region above the pubic bone may be caused by a relative immobility of the skin. In 1997, Pinheiro et al.¹⁰ compared the performance of polybutester sutures to that of nylon sutures in 70 male and female rats in which they examined the clinical response of the skin in abdominal wall muscle to the use of these sutures. Under general anesthesia, standard wounds were created in the dorsum and abdomen of the animals and subjected to suture closure with either polybutester or nylon. The animals were sacrificed immediately, 12, 24, and 72 hours and at four, five and seven days to evaluate the impact of the sutures on the wounds. They found that polybutester produced some advantages such as strength, lack of package memory, elasticity, and flexibility which made suturing quicker and easier. They concluded that Novafil™ suture can be used safely on skin and mucosal wounds because it is less irritating to tissues than nylon.

The clinical performance of polybutester suture has been enhanced by coating its surface with a unique absorbable polymer (Vascufil™).¹¹ The coating is a poly-tribolate polymer that is composed of three compounds: glycolide, ε-caprolactone,

and poloxamer 188. Coating the polybutester suture markedly reduces its drag forces in musculoaponeurotic, colonic, and vascular tissue. Knot security with the Vasculfil™ suture was achieved with only one more throw than with comparably sized, uncoated polybutester sutures. On the basis of the results of our investigations, coating the polybutester suture represents another major advance in surgical suture performance.

2. Absorbable surgical sutures

The absorbable sutures of Covidien are made from either collagen or synthetic polymers. The collagen sutures are derived from the serosal layer of bovine small intestine (gut). This collagenous tissue is treated with an aldehyde solution, which cross-links and strengthens the suture and makes it more resistant to enzymatic degradation. Suture materials treated in this way are called plain gut (Plain Gut). If the suture is additionally treated with chromium trioxide, it becomes chromic gut (Chromic Gut), which is more highly cross-linked than plain gut and more resistant to absorption. When this treatment of collagen sutures is limited, the result is a special form of chromic gut (Mild Gut) that is more susceptible to tissue absorption. The plain gut and chromic gut sutures are composed of several plies that have been twisted

III. scientific basis for the selection of surgical sutures (cont'd)

slightly, machine ground, and polished, yielding a relatively smooth surface that is monofilament-like in appearance. Salthouse and colleagues¹² demonstrated that the mechanism by which gut reabsorbs is the result of sequential attacks by lysosomal enzymes. In most locations, this degradation is started by acid phosphatase, with leucine aminopeptidase playing a more important role later in the absorption period. Collagenase is also thought to contribute to the enzymatic degradation of these collagen sutures.

Natural fiber absorbable sutures have several distinct disadvantages. First, these natural fiber absorbable sutures have a tendency to fray during knot construction. Second, there is considerably more variability in their retention of tensile strength than is found with the synthetic absorbable sutures. A search for a synthetic substitute for collagen sutures began in the 1960s. Soon procedures were perfected for the synthesis of high molecular weight polyglycolic acid, which led to the development of the polyglycolic acid sutures (Dexon™ II, Dexon™ S).¹³ These sutures are produced from the homopolymer, polyglycolic acid. Because of the inherent rigidity of this homopolymer, monofilament sutures produced from polyglycolic acid sutures are too stiff for surgical use. This homopolymer

can be used as a monofilament suture only in the finest size. Consequently, this high molecular weight homo-polymer is extruded into thin filaments and braided.¹³ The thin filaments of Dexon™ II are coated with Polycaprolate™, a copolymer of glycolide and epsilon-caprolactone, to reduce the coefficient of friction encountered in knot construction. Dexon™ S is an uncoated braided suture. The polyglycolic acid sutures (Dexon™ II, Dexon™ S) degrade in an aqueous environment through hydrolysis of the ester linkage.

Copolymers of glycolide and lactide were then synthesized to produce a Lactomer™ copolymer that is used to produce a new braided absorbable suture (Polysorb™). The glycolide and lactide behaved differently when exposed to tissue hydrolysis. Glycolide provides for high initial tensile strength, but hydrolyses rapidly in tissue.¹³ Lactide has a slower and controlled rate of hydrolysis, or tensile strength loss, and provides for prolonged tensile strength in tissue.¹³

The Lactomer™ copolymer consists of glycolide and lactide in a 9:1 ratio.

The handling characteristics of the Polysorb™ sutures were found to be superior to those of the Polyglactin 910™ suture.¹⁴ Using comparable knot construction and

III. scientific basis for the selection of surgical sutures (cont'd)

suture sizes, the knot breaking strength for Polysorb™ sutures was significantly greater than that encountered by Polyglactin 910™ sutures. In addition, the mean maximum knot rundown force encountered with the Polysorb™ sutures was significantly lower than that noted with the Polyglactin 910™ sutures, facilitating knot construction.

The surfaces of the Polysorb™ sutures have been coated to decrease their coefficient of friction.¹⁴ The new Polysorb™ suture is coated with an absorbable mixture of caprolactone/glycolide copolymer and calcium stearoyl lactylate. At 14 days post-implantation, nearly 80% of the USP (United States Pharmacopoeia) tensile strength of these braided sutures remains. Approximately 30% of their USP tensile strength is retained at 21 days. Absorption is essentially complete between days 56 and 70.

We recently studied the determinants of suture extrusion following subcuticular closure by synthetic braided absorbable sutures in dermal skin wounds.¹⁵ Miniature swine were used to develop a model for studying suture extrusion. Standard, full-thickness skin incisions were made on each leg and the abdomen.

The wounds were closed with size 4/0 Polysorb™ or Coated Vicryl™ (Ethicon, Inc., Somerville, NJ) sutures. Each incision was closed with five interrupted, subcuticular, vertical loops secured with a surgeon's knot. The loops were secured with 3-throw knots in one pig, 4-throw knots in the second pig, and 5-throw knots in the third pig. The swine model reproduced the human clinical experience and suture extrusion, wound dehiscence, stitch abscess, and granuloma formation were all observed. The cumulative incidence of suture extrusion over 5 weeks ranged from 10 to 33%. Coated Vicryl™ sutures had a higher mean cumulative incidence of suture extrusion than that of Polysorb™ sutures (31% vs. 19%). With Polysorb™ sutures, the 5-throw surgeon's knots had a higher cumulative incidence of suture extrusion than the 3-throw or 4-throw surgeon's knot square, 30% vs. 17% and 10%, respectively. This swine model offers an opportunity to study the parameters that influence suture extrusion. Because the volume of suture material in the wound is obviously a critical determinant of suture extrusion, it is imperative that the surgeon construct a knot that fails by breakage, rather than by slippage with the least number of throws. Because both braided absorbable suture materials are constructed with a secure surgical knot that fails only by breakage rather than slippage with a 3-throw surgeon's knot square ($2 = 1 = 1$), the

III. scientific basis for the selection of surgical sutures (cont'd)

construction of additional throws with these sutures does not enhance the suture holding capacity, but plays a key factor in precipitating suture extrusion. Finally, it is important to emphasize that the surgeon must always construct symmetrical surgical knots for dermal subcuticular skin closure in which the constructed knot is always positioned perpendicular to the linear wound incision. Asymmetrical knot construction for dermal wound closure becomes an obvious invitation for suture extrusion.

A monofilament absorbable suture (Maxon™) has been developed using trimethylene carbonate.¹⁶ Glycolide trimethylene carbonate is a linear copolymer made by reacting trimethylene carbonate and glycolide with diethylene glycol as an initiator and stannous chloride dihydrate as the catalyst. The strength of the monofilament synthetic absorbable suture, glycolide trimethylene carbonate (Maxon™), is maintained in vivo much longer than that of the braided synthetic absorbable suture. This monofilament suture retained approximately 50% of its breaking strength after implantation for 28 days, and still retained 25% of its original strength at 42 days. In contrast, braided absorbable sutures retained only 1% to 5% of their strength at 28 days. Absorption of the trimethylene carbonate

suture is minimal until about the 60th day post-implantation and essentially complete within six months.

Another innovation in the development of monofilament synthetic absorbable sutures has been the production of Glycomer 631, a terpolymer composed of glycolide (60%), trimethylene carbonate (26%), and dioxanone (14%) (Biosyn™). The Biosyn™ suture has many distinct advantages over the braided synthetic absorbable sutures.¹⁷ First, this monofilament suture is significantly stronger than the braided synthetic absorbable suture over four weeks of implantation. It maintains approximately 75% of its USP tensile strength at two weeks and 40% at three weeks post-implant. Absorption is complete between 90 to 110 days. Due to its construction, Monofilament suture potentiates less bacterial infection than does the braided suture. The handling characteristic of this monofilament suture is superior to the braided suture because it encounters lower drag forces in the tissue than does the braided suture.

The latest innovation in the development of monofilament absorbable sutures has been the rapidly absorbing Caprosyn™ suture. Caprosyn™ monofilament synthetic

III. scientific basis for the selection of surgical sutures (cont'd)

absorbable sutures are prepared from Polyglytone™ 6211 synthetic polyester which is composed of glycolide, caprolactone, trimethylene carbonate, and lactide. Implantation studies in animals indicate that Caprosyn™ suture retains a minimum of 50-60% USP knot strength at five days post implantation, and a minimum of 20-30% of knot strength at 10 days post implantation. All of its tensile strength is essentially lost by 21 days post implantation.

We recently have compared the biomechanical performance of Caprosyn™ suture to that of Chromic Gut suture.¹⁸ The biomechanical performance studies included quantitative measurements of wound security, strength loss, mass loss, potentiation of infection, tissue drag, knot security, knot rundown, as well as suture stiffness. Both Caprosyn™ and Chromic Gut sutures provided comparable resistance to wound disruption. Prior to implantation, suture loops of Caprosyn™ had a significantly greater mean breaking strength than suture loops of Chromic Gut. Three weeks after implantation of these absorbable suture loops, the sutures had no appreciable strength. The rate of loss of suture mass of these two sutures was similar. As expected, Chromic Gut sutures potentiated significantly more infection than did the Caprosyn™ sutures.

The handling properties of the Caprosyn™ sutures were far superior to those of the Chromic Gut sutures. The smooth surface of the Caprosyn™ sutures encountered lower drag forces than did the Chromic Gut sutures. Furthermore, it was much easier to reposition the Caprosyn™ knotted sutures than the knotted Chromic Gut sutures. In the case of Chromic Gut sutures, it was not possible to reposition a two-throw granny knot. These biomechanical performance studies demonstrated the superior performance of synthetic Caprosyn™ sutures compared to Chromic Gut sutures and provide compelling evidence of why Caprosyn™ sutures are an excellent alternative to Chromic Gut sutures.

The direct correlation of molecular weight and breaking strength of the synthetic absorbable sutures with both in vivo and in vitro incubation implies a similar mechanism of degradation. Because in vitro incubation provides only a buffered aqueous environment, the chemical degradation of these sutures appears to be by non-enzymatic hydrolysis of the ester bonds. Hydrolysis would be expected to proceed until small, soluble products are formed, then dissolved, and removed from the implant site. In contrast, the gut or collagen suture, being a proteinaceous substance, is degraded primarily by the action of proteolytic enzymes.

III. scientific basis for the selection of surgical sutures (cont'd)

A distinction must be made between the rate of absorption and the rate of tensile strength loss of the suture material. The terms rate of absorption and rate of tensile strength loss are not interchangeable. Although the rate of absorption is of some importance with regard to late suture complications, such as sinus tracts and granulomas, the rate of tensile strength loss is of much greater importance to the surgeon considering the primary function of the suture, maintaining tissue approximation during healing.

When considering an absorbable suture's tensile strength in vivo, we recommend that the manufacturer provide specific measurements of its holding capacity, rather than the percentage retained of its initial tensile strength. The United States Pharmacopoeia (USP) has set tensile strength standards for synthetic absorbable suture material. If the manufacturers were to use these standards to describe maintenance of tensile strength, the surgeon would have a valid clinical perspective to judge suture performance. Some manufacturers persist in reporting maintenance of the tensile strength of their suture in tissue by referring only to the percentage retained of its initial tensile strength, making comparisons between

sutures difficult. The need to use USP standards in reporting is particularly important when there are marked differences in the initial tensile strengths of the synthetic sutures. For example, the initial tensile strength of Biosyn™ is 43% stronger than that of polydioxanone. At two weeks, the Biosyn™ suture is approximately 30% stronger.

IV. components of a knotted suture loop using either a granny knot type or a square knot type

The mode of operation of a suture is the creation of a loop of fixed perimeter secured in the geometry by a knot.¹⁹ A tied suture has three components (Figure 1). First, the loop created by the knot maintains the approximation of the divided wound edges. Second, the knot is composed of a number of throws snugged against each other. A throw is a wrapping or weaving of two strands. Finally, the “ears” act as insurance that the loop will not become untied because of knot slippage. The doctor’s side of the knot is defined as the side of the knot with “ears,” or the side to which tension is applied during tying. The patient’s side is the portion of the knot adjacent to the loop.

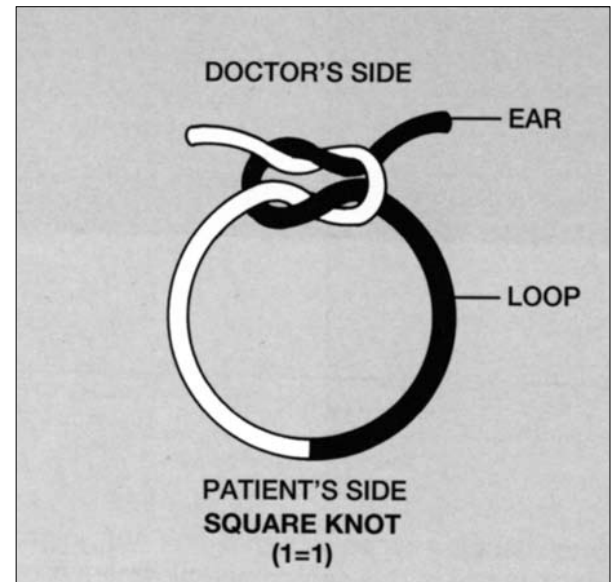
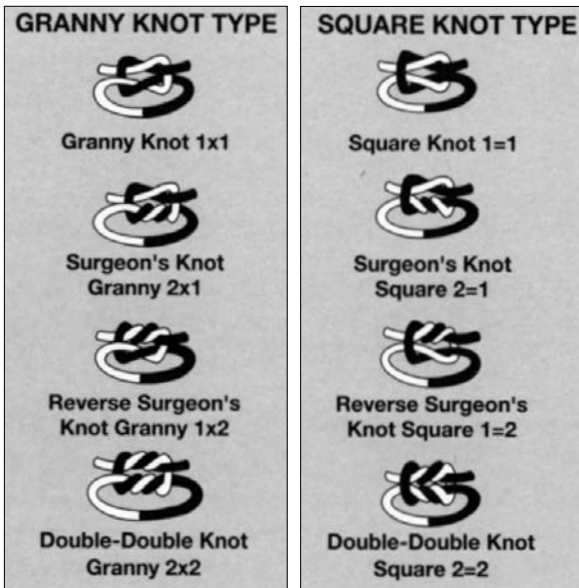


Figure 1. The components of a tied suture.

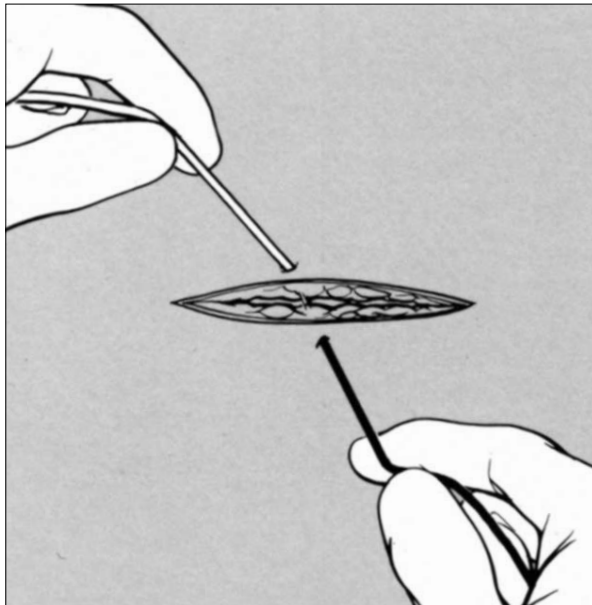


Each throw within a knot can either be a single or double throw. A single throw is formed by wrapping the two strands around each other so that the angle of the wrap equals 360° . In a double throw, the free end of a strand is passed twice, instead of once, around the other strand; the angle of this double-wrap throw is 720° . The tying of one or more additional throws completes the knot. The configuration of the knot can be classified into two general types by the relationship between the knot “ears” and the loop (Figure 2). When the right “ear” and the loop of the two throws exit on the same side of the knot or parallel to each other, the type of knot is judged to be square (reef). The knot is considered a granny type if the right “ear” and the loop exit or cross different sides of the knot.

When the knot is constructed by an initial double-wrap throw followed by a single throw, it is called a surgeon’s (friction) knot. The configuration of a reversed surgeon’s knot is a single throw followed by a double-wrap throw. A knot consisting of two double-wrap throws is appropriately called a double-double.

Figure 2. The configuration of surgical knots.

IV. components of a knotted suture loop (cont'd)



When forming the first throw of either a square or granny knot, the surgeon is merely wrapping one suture end (360°) around the other, with the suture ends exiting in opposite directions. The surgeon will apply equal and opposing tension to the suture ends in the same planes. The direction of the applied tensions will be determined by the orientation of the suture loop in relation to that of the surgeon's hands. When the surgeon's hands lie on each side and parallel to the suture loop, the surgeon will apply tensions in a direction parallel to his/her forearms. (Figure 3).

Figure 3. During knot construction, the surgeon's hands should be on each side and parallel to the suture loop

Tension will be applied to the farther suture end in a direction away from the surgeon. Conversely, an equal opposing force will be applied to the closer suture end in a direction toward the surgeon. After constructing the second throw of these knots, the direction of the suture ends must be reversed, with an accompanying reversal of the position of the surgeon's hand. As the surgeon's hands move toward or away from his body, the movements of his right and left hands are in separate and distinct areas that do not cross, permitting continuous visualization of knot construction. With each additional throw, the surgeon must reverse the position of his/her hands.

Orientation of the suture loop in a plane that is perpendicular to that of the surgeon's forearms considerably complicates knot construction (Figure 4). In this circumstance, reversal of the position of the hands occurs in the same area, with crossing and overlapping of the surgeon's hands, temporarily obscuring visualization of knot construction. This circumstance may be encountered when constructing knots in a deep body cavity, which considerably limits changes in hand positions. This relatively cumbersome hand position may interfere with the application of uniform opposing tensions to the suture ends, an invitation to the conversion of a square knot construction to a slip knot.

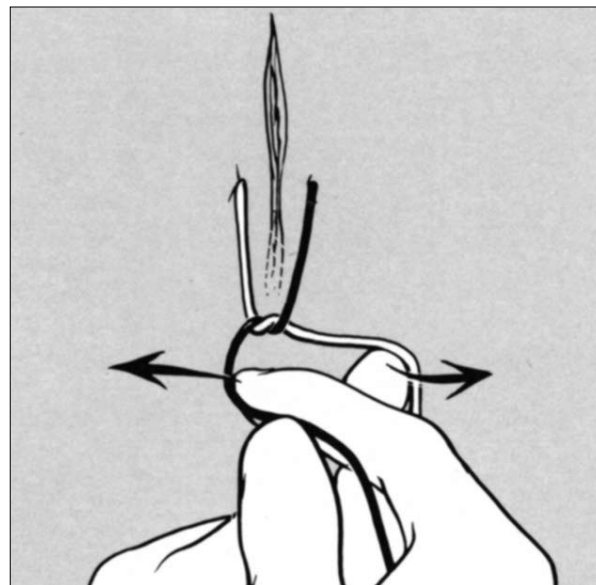
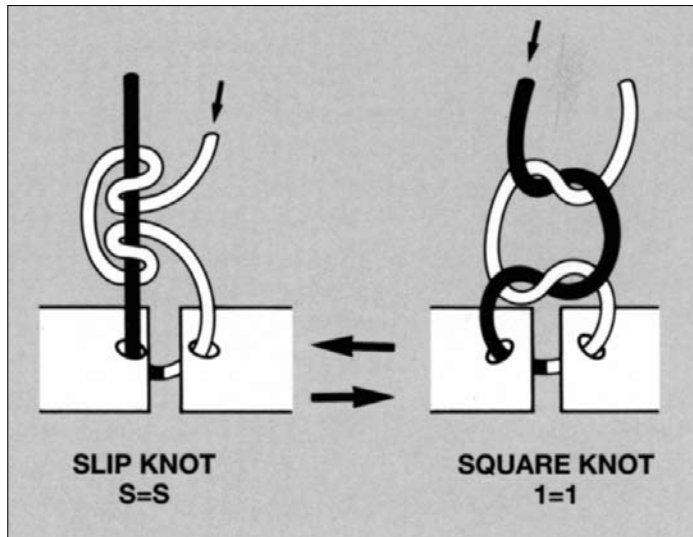


Figure 4. The surgeon's hands frequently overlap (arrows) when the orientation of the hands is perpendicular to that of the suture loop.

IV. components of a knotted suture loop (cont'd)



The granny knot and square knot can become a slip knot by making minor changes in the knot tying technique (Figure 5). Surgeons who do not reverse the position of their hands after forming each throw will construct slip knots. Furthermore, the application of greater tension to one "ear" than the other encourages construction of slip knots, a practice commonly encountered in tying deep-seated ligatures.²⁰

Figure 5. When the tension (arrow) is reapplied in equal and opposing directions, the slip knot can be converted into a square knot.

When the tension is reapplied in equal and opposing directions, the slip knots can usually be converted into either the square or granny knots. A simple code has been devised to describe a knot's configuration (Figure 2).²¹ The number of wraps for each throw is indicated by the appropriate Arabic number. The relationship between each throw being either crossed or parallel is signified by the symbols X or =, respectively. In accordance with this code, the square knot is designated 1=1, and the granny knot 1x1. The presence of a slip knot construction is indicated by the letter S. This method of describing knots facilitates their identification and reproduction. It is, for example, perfectly obvious what is meant by 2x2x2, without giving the knot a name, and all surgical knots can be defined unequivocally in this international language.

Sutures remain the most common method of approximating the divided edges of skin. Skin closure can be achieved by either percutaneous suture closure, dermal suture closure, or a combination of both techniques. Dermal or percutaneous suture closures are accomplished by either interrupted suture or a continuous suture closure technique.

When utilizing a continuous suture, the first suture loop is constructed by using the single strand of the fixed suture end attached to the needle and a single strand of the free suture end. However, the knot of the last suture loop at the end of the continuous suture is constructed by a suture loop containing two strands and the single strand of the fixed suture end attached to the needle.

IV. components of a knotted suture loop (cont'd)

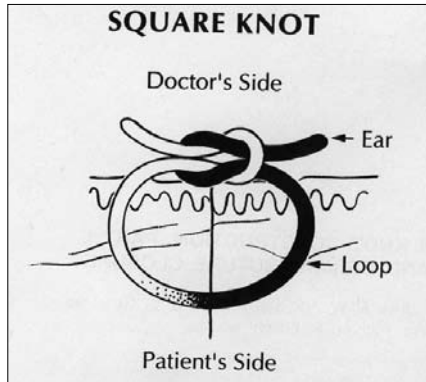


Figure 6. Construction of a square knot with two single strands.

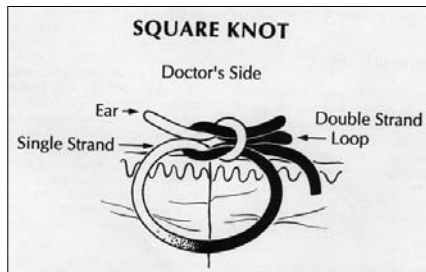


Figure 7. Construction of a square knot with a single strand and suture loop.

The first knot in a percutaneous and dermal suture closure usually has a square knot construction. A tied square knot suture has three components (Figure 6). The loop created by the knot maintains the apposition of tissue. The knot is composed of a number of throws secured against each other. The ears are the cut ends of the suture, which add security to the knot by preventing untying during slippage.

At the end of a percutaneous and dermal closure, the knot must be constructed as a square knot with a single strand and a suture loop. A square knot of an interrupted suture loop is formed by two single throws in which the right ear and loop come out in a position that is directly opposite to that of the left ear and loop. The configuration of a knot using a looped suture end and a fixed suture end attached to a needle is markedly different from the interrupted knotted suture loop in which knot construction is accomplished by two separate strands of sutures. The interrupted suture has a knot constructed by two single strands. In contrast, knots constructed with a suture loop have two suture strands that

are intertwined with the single strand of the fixed suture end. When knot construction is complete, the interrupted percutaneous suture has two cut suture ends. Knots constructed by a double-strand suture loop and a single strand of the fixed suture end has three separate knot ears (Figure 7). The square knot is formed when the right ear and the loop of a two-throw knot exit on the same side of the knot and are parallel to each other.

During wound closure, knot construction involves two steps. The first secures precise approximation of the wound edges by advancing either a one-throw or a two-throw knot to the wound surface. The second step is the construction of additional throws until knot security is attained and slippage is prevented.²²

Our biomechanical performance studies demonstrate that secure knot configuration of the interrupted suture loop created at the beginning of the wound is quite different from secure knot configuration of the knot constructed at the end of the wound. These differences in secure knot configurations are related to the types of suture strands used in knot construction. The first knot in a continuous suture is constructed by two single strands, and the second knot is created by a single strand and a suture loop. Knot construction with a suture loop predisposes the knot to suture slippage and requires additional throws for knot security. When constructing the first interrupted suture loop with either absorbable or nonabsorbable monofilament sutures, knot security is achieved with square knot construction by using three or four throws. The last suture loop and single strand involves at least five or six throws for knot security. If the trauma surgeon fails to construct secure knots at the beginning or the end of the laceration, knot slippage will occur, resulting in wound dehiscence.

V. mechanical performance

The mechanical performance of a suture is an important consideration in the selection of a surgical suture and can be measured by reproducible, biomechanical parameters.²³ The suture's stiffness reflects its resistance to bending. Its coefficient of friction is a measure of the resistive forces encountered by contact of the surfaces of the suture material during knot construction. Strength is a key performance parameter that indicates the suture's resistance to breakage. The knot breakage load for a secure knot that fails by breakage is a reliable measure of strength. During these tests, forces are applied to the divided ends of the suture loop, the patient's side of the knot. As the suture is subjected to stress, it will elongate. The load elongation properties of a suture have important clinical implications. Ideally, the suture should elongate under low loads to accommodate for the developing wound edema, but return to its original length after resolution of the edema. Although it should exhibit an immediate stretch under low loads, it should not elongate any further while continuously maintaining the load, exhibiting a resistance to creep.

These biomechanical parameters play important roles in the clinical performance of the suture.²⁴ Surgeons consider the handling characteristics of the suture to be one of the most important parameters in their selection of sutures. Surgeons evaluate the handling characteristics of sutures by constructing knots using manual and instrument-tie techniques. The surgeon prefers a suture which permits two-throw knots to be easily advanced to the wound edges, providing a preview of the ultimate

apposition of the wound edges. The force required to advance the knot is called knot rundown force. Once meticulous approximation of the wound edges is achieved, the surgeon prefers to add one more throw to the two-throw knot so that it does not fail by slippage.

The magnitude of the knot rundown force is influenced considerably by the configuration of two-throw knots. ²⁴ Knot rundown of the surgeon's knot square (2=1) generates sufficient forces to break the knot. In contrast, knot rundown of square (1=1), granny (1x1) and slip (S=S, SxS) knots occurs by slippage. For comparable sutures, the mean knot rundown force for square knots is the greatest, followed by that for the granny (1x1) knots, and then the slip (S=S, SxS) knots.

Failure of the knotted suture loop may be the result of either knot slippage or breakage, suture cutting through tissues, and mechanical crushing of the suture by surgical instruments. Initially, the knotted suture fails by slippage, which results in untying of the knot. All knots slip to some degree regardless of the type of suture material. When slippage is encountered, the cut ends ("ears") of the knot must provide the additional material to compensate for the enlarged suture loop. When the amount of knot slippage exceeds the length of the cut "ears," the throws of the knot become untied. In general, surgeons recommend that the length of the knot "ears" be 3mm to accommodate for any knot slippage. 3 Dermal sutures are, however, an exception to this rule. Because the "ears" of dermal suture knots may protrude through the divided skin edges, surgeons prefer to cut their dermal suture "ears" as they exit from the knot. It must be emphasized that knot security is achieved in a knot with "ears" with one more throw than in a comparable knot whose "ear" length is 3mm.

knot slippage

Knot slippage is counteracted by the frictional forces of the knots. The degree to which a knot slips can be influenced by a variety of factors including the coefficient of friction of the suture material, suture diameter, moisture, knot type and final geometry. Knots of the granny type (crossed) usually exhibit more slippage than do knots with a square-type (parallel) construction.

With each additional throw, incrementally greater forces are required for knot untying. After a specified number of throws, failure will occur by knot breakage, after which the knot breakage force will not be enhanced by the addition of more throws. Consequently, these additional throws offer no mechanical advantage and represent more foreign bodies in the wound that damage host defenses and resistance to infection.

The human element in knot tying has considerable influence on the magnitude of knot slippage.¹⁹ The amount of tension exerted by the surgeon on the “ears” of the knot significantly alters the degree of slippage. The careless surgeon who applies minimal tension (10% of knot break strength) to the “ears” of the knot constructs knots that fail by slippage. Knot slippage can be minimized by applying more tensions (80% of knot break strength) to the “ears” of the knot. Another serious error often made by the inexperienced surgeon is not to change the position of his/her hands appropriately during construction of square and/or granny type knots. The resulting knot, a sliding or slip knot, will become untied regardless of the suture material. The risk of forming a slip knot is greatest when tying one-hand knots and/or with deep seated ligatures.²⁰⁻²³

knot breakage

When enough force is applied to the tied suture to result in breakage, the site of disruption of the suture is almost always the knot. The force necessary to break a knotted suture is lower than that required to break an untied suture made of the same material.¹⁹ The forces exerted on a tied suture are converted into shear forces, by the knot configuration that break the knot. The percentage loss of tensile strength, as a result of tying a secure knot, is least with mono-filament and multifilament steel.²⁵ This relationship between the tensile strength of unknotted and knotted suture which is designated knot efficiency, is described in the following equation:

$$\text{Knot efficiency (\%)} = \frac{\text{tensile strength of a knotted suture}}{\text{tensile strength of unknotted suture}}$$

Regardless of the type of suture material, the efficiency of the knot is enhanced with an increasing number of throws, although only up to a certain limit.

The type of knot configuration that results in a secure knot that fails by breaking varies considerably with different suture material. The magnitude of force necessary to produce knot breakage is influenced by the configuration of the knotted suture loop, type of suture material, and the diameter of the suture.³ The tissue in which the suture is implanted also has considerable influence on the knot strength of suture. In the case of absorbable sutures, a progressive decline in knot breaking strength is noted after tissue implantation. In addition, the magnitude of knot breakage force is significantly influenced by the rate of application of forces to the “ears” of the knot.²³ When a constant force is applied slowly to the knot “ears,” the knot breakage force is significantly greater than that for knots in which the same constant force is applied rapidly to the “ears.” The latter knot loading rate is often referred to as “the jerk at the end of the knot,” especially when the knotted suture breaks.

suture cutting tissue

Suture failure also may occur if the knotted suture loop cuts through the tissue. The type of tissue has considerable influence on the magnitude of force required to tear the suture through the tissue. Howes and Harvey²⁶ reported that the forces required to tear gut sutures through canine fascia was the greatest followed by muscle, peritoneum and then fat. Using cadaver specimens 6 to 93 days after death, Tera and °Aberg²⁷ measured the magnitude of forces required for suture to tear through excised musculoaponeurotic layers of laparotomy incisions. The rationale for this study was that the forces required to tear sutures through a musculoaponeurotic layer would provide a basis for the choice of a suture whose strength is at least as strong as the forces required to tear the suture through the tissue. When the suture was passed lateral to the transition between the linea alba and the rectus sheath, the force required to tear the suture through the tissue was greater than that for any other musculoaponeurotic layer tested; the paramedian incision required the lowest forces to pull sutures through its sheaths. When they recorded the forces needed for sutures to tear through structures involved in the repair of inguinal hernia, the structures making up the conjoined tendon and Cooper's ligament were the strongest and exhibited twice the resistance to suture tearing than those of the other structures.

As expected, the force required for sutures to tear through tissue changes during healing. Aberg²⁸ reported that the forces needed for sutures to tear through the aponeurotic muscle layer reduced significantly during the first week of healing. When the wound edges were approximated by suture tied tightly around this aponeurotic muscle layer, the reduction in force needed for the suture to pull through this tissue persisted for two weeks.

mechanical trauma

Mechanical trauma to the suture by surgical instruments can also result in suture failure. Nichols et al²⁹ cautioned surgeons about the handling of sutures by surgical instruments. They indicated that either the application of clamps and forceps to the suture or rough handling of sutures could damage and weaken them. Stamp et al³⁰ incriminated the teeth in the needle holder jaws as important causal factors of sutural damage. Compression of sutures between the needle holder jaws with teeth produced morphologic changes in sutures that resulted in a marked reduction in the suture breaking strength. Similarly, the sharp edges of needle holder jaws without teeth can even crush the suture and, thereby, decrease its strength.³¹ Finally application of large compressive loads by pinching polypropylene sutures with DeBakey forceps decreases the strength of the suture.³²

VI. tying techniques

The surgeon may use an individual ligature (“free tie”) or a suture that is attached to a needle or ligature reel. The length of a free tie or suture attached to a needle is usually 18 inches. The longest strands of suture material are available on a reel or spool. When the suture is attached to a needle or reel, there is a free end and a fixed end; the fixed end is attached to either the needle or reel. The first throw of a knot is accomplished by wrapping the free end either once or twice (surgeon’s) around the fixed end. During practice, clamp one end of the suture with an instrument that serves to represent either the needle or the reel, which is the fixed end of the suture.

Formation of each throw of a knot is accomplished in three steps. The first step is the formation of a suture loop. In the second step, the free suture end is passed through the suture loop to create a throw. The final step is to advance the throw to the wound surface. For the first throw of a square, granny, and surgeon’s knot square, for each additional throw the direction in which tension is applied to the suture ends is reversed. The surgeon should construct a knot by carefully snugging each throw tightly against another. The rate of applying tension to each throw should be relatively slow.

For either the square knot or surgeon’s knot square, the direction in which the free suture end is passed through the loop will be reversed for each additional throw. If the free suture end is passed down through the first suture loop, it must be passed up through the next suture loop. Reversal of the direction of passage of the free suture end through the loops does not alter either the knot’s mechanical performance or its configuration. It simply reverses the presentation of the knot (Figure 8). For granny knots, the direction in which the free suture end is passed through the loop is the same for each additional throw.

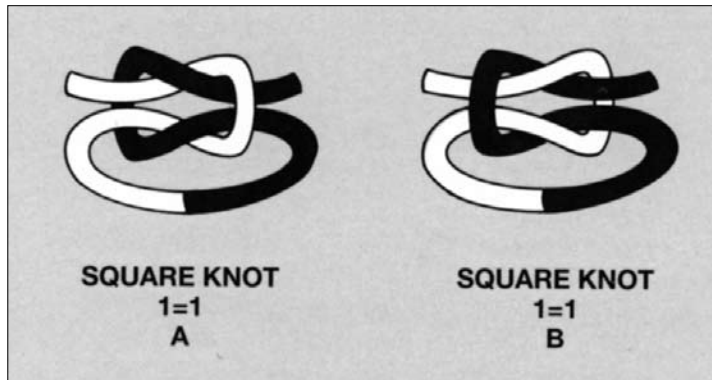


Figure 8. Square knot (1=1) (A) is formed by first passing the free suture end up through the suture loop to create the first throw. The second throw is formed by passing the free suture end down through the suture loop. Square knot (1=1) (B) is formed by passing the free suture end down through the suture loop to create the first throw. The second throw is formed by passing the free suture end up through the suture loop.

During surgery, knot construction involves two distinct steps. The purpose of the first step is to secure precise approximation of the wound edges by advancing either a one-throw or a two-throw knot to the wound surface. Once the throw or throws contact the wound, the surgeon will have a preview of the ultimate apposition of the wound edges. Ideally, the knotted suture loop should reapproximate the divided wound edges without strangulating the tissue encircled by the suture loop. If there is some separation of the wound edges, the one-throw or two-throw knot can be advanced to reduce the size of the suture loop and thereby bring the wound edges closer together.

When the surgeon forms a double-wrap throw, the first throw of the surgeon's knot square (2=1) can maintain apposition of the wound edged by "locking" or temporarily securing it in place by reversing the direction of pull on its "ears." The "locked" double throw is not

VI. tying techniques (cont'd)

a reliable means of maintaining wound apposition because any tension applied to the “ears” from the patient’s side of the knot will unlock the knot. The addition of the second throw to the surgeon’s knot square (2=1) will provide additional resistance to wound disruption, but this knot will not advance by slippage, limiting the surgeon’s ability to secure meticulous coaptation of the wound edges.²⁴

In contrast, two-throw square (1=1) or granny (1x1) knots can be advanced to the wound surface to secure precise wound edge apposition. These two-throw square (1=1) or granny (1x1) knots can be easily converted into their respective slip knots by applying tension to only one “ear” in a direction that is perpendicular to that of the tissue surface. Square (S=S) or granny (SxS) slip knots require lower knot rundown force for knot advancement than either the square (1=1) or granny (1x1) knots, but will never reach knot security even with 5 throws.⁹ The risk of tying slip knots can be obviated by applying tensions to both “ears” in horizontal planes parallel to the tissue surface. The second step in knot construction is the addition of a sufficient number of throws to the knot so that it does not fail by slippage. The magnitude of knot breakage force is always greater than that for knot slippage force of a comparable suture, ensuring optimal protection against wound dehiscence. The magnitude of knot breakage force is significantly influenced by the rate of application of forces to the knot. When constant force is applied slowly to the knot “ears,” the knot breakage force is significantly greater than that for knots in which the same constant force is applied rapidly to the “ears.”

instrument tie

Knot construction can be accomplished by either an instrument or hand tie. An instrument tie occurs by the formation of suture loop over an instrument, usually a needle holder. The right hand holds the needle holder, while the left hand loops the fixed suture end around the instrument. The position of the instrument in relation to the suture ends during knot construction will determine the type of knot. When the instrument is placed above the fixed suture end during the first and second throws, a square-type knot will develop. In contrast, a granny-type knot will first result when the instrument is placed above the fixed suture end for the first throw and then below the fixed suture end for the second throw. By repeating this positioning, the instrument tie is a reliable and easy method to produce multiple throw granny knots (1x1x1), a circumstance not encountered in hand ties. Granny knots with more than two throws cannot be constructed by either the one-hand or two-hand technique, without releasing hold of both suture ends.

Instrument tying is accomplished primarily by the surgeon's left hand, which holds the fixed suture end. Initially the length of the fixed suture end held by the left hand is long (17 in.), making it difficult to form knots without injuring the attending assistant. This assault can be avoided by shortening the length of the fixed suture end held by the left hand. Preferably, the fixed suture end should be coiled into loops, which are held between the tips of the thumb and index finger.

instrument tie (cont'd)

This maneuver is accomplished by first grasping the fixed suture end with the small and ring fingers, while it is being pinched between the tips of the index finger and thumb. By pronating the wrist, a loop forms around the grasped fingers, and the top of the loop must again be grasped between the tips of the thumb and index fingers. The small and ring fingers are then withdrawn from the loop before coiling more suture. The rasped suture can be easily lengthened by releasing the coils held between the tips of the thumb and index finger.

When tying knots with an instrument, it is difficult to apply continuous tension to the suture ends. Consequently, widening of the suture loop due to slippage is frequently encountered in wounds subjected to strong tension. This technique, however, is ideally suited for closing a wound which is subjected to weak tensions. In this circumstance, instrument ties can be accomplished more rapidly and accurately than hand ties, while conserving considerably more suture. By using this technique, the parsimonious surgeon can complete 10 interrupted suture loops from one suture measuring 18 inches in length. This feat would be impossible if the knots had been tied by hand.

The value of instrument ties has become readily apparent in special situations in which hand ties are impractical or impossible. In microsurgical procedures, an instrument tie provides the most reliable and easiest method of knot construction. When employing suture in the recesses of the body (e.g. mouth, vagina, etc.) or during endoscopic surgery, instruments can also form knots in sites to which the hand could never gain access.

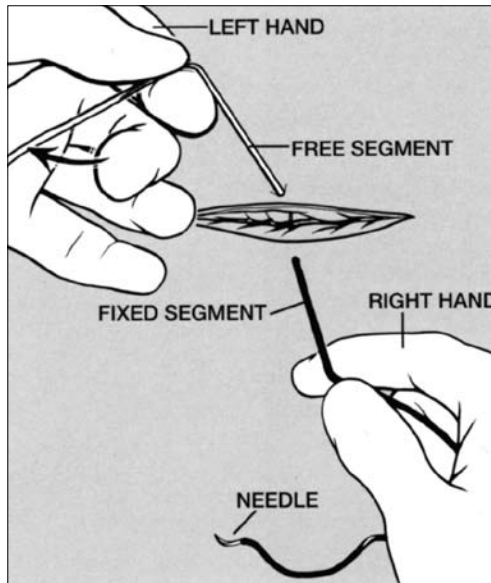
hand tie

Hand tying of knots can be accomplished by either the two-hand or one-hand technique. Each technique has distinct advantages as well as drawbacks. The two-hand technique of knot tying is easier to learn than the one hand. An additional advantage of the two-hand tie is that the surgeon can apply continuous tension to the suture ends until a secure knot is formed. With the one-hand method, it is often difficult to maintain tension on the suture ends during the formation of the knot and slippage of the first or second throws will be encountered, especially by the inexperienced surgeon. When the surgeon attempts to shorten the resultant enlarged loop by advancing the knot, breakage of the suture may occur, requiring passage of another suture through the once punctured tissue. The student of surgery should master first the construction of square type knots because knot security can usually be achieved with fewer throws than the granny-type knots.²¹ The additional foreign bodies required to form a secure granny knot, predisposes the wound to the development of infection.

The hand-tying techniques illustrated in this manual are those used by right-handed individuals. Using the two-hand technique, he/she constructs the knot predominantly with his/her left hand, which forms a suture loop through which the free suture end is passed. The left hand continually holds the suture end until knot construction is complete. In contrast, the right hand merely holds, lets go, and regrasps the free suture end. If the surgeon inadvertently manipulates the fixed suture end with his/her right hand, he/she will be passing either the needle or reel through the formed loop. The latter case is an invitation to needle puncture.

Many right-handed surgeons prefer to manipulate the free end of the suture with their left and during two-hand ties. In such cases, the right hand performs the major manipulation of the suture during formation of the loop. An advantage of this

hand tie (cont'd)



technique is that a surgeon who ties his/her own knots by the two-hand technique during wound closure can hold the needle holder in his/her right hand during knot construction. If one desired to learn to tie knots using the left hand to manipulate the free end of the suture, study the illustrations in a mirror.

Using the one-hand tie, one hand forms the suture loop while manipulating the free suture end. The other hand merely holds the mother suture end taut. Most surgeons prefer to manipulate the free suture end with their left hand, allowing them to hold the needle holder in their right hand while they construct knots with their left hand.

There are several important recommendations for selecting a knot tying technique. First, position the hands on each side of and parallel to the suture loop. Second, grasp the appropriate suture ends and form the suture loop, without exchanging suture ends between the hands. While exchanging suture ends between the hands forms a triangular-shaped suture loop, it is an unnecessary step that wastes valuable time. Third pass the free suture end, rather than the fixed suture end, through the suture loop. Finally, reverse the position of the hands after

Figure 9. Standard format for illustrating the knot tying technique.

each additional throw. Most of the knot tying techniques in this manual comply with these recommendations. However, it is important to point out that the fixed end of the suture is being passed through the suture loops in the two-hand ties. Consequently, the surgeon must detach the needle from the fixed suture end before a two-hand tie.

A standard format for illustrating surgical knot tying techniques has been used throughout the manual (Figure 9). A horizontal incision is pictured in the top of each illustration. Because the wound edges are subjected to static tensions, there is retraction of the wound edges, with exposure of the underlying tissue. The surgeon is standing facing the wound from the bottom of each illustration. Because the surgeon usually passes the needle swaged to a suture toward himself (herself), the fixed end (black) of the suture with its attached needle enters the farther side of the mid-portion of the wound and exits from the side of the wound closer to the surgeon. The free end of the suture is white to facilitate illustration of the knot tying technique. The suture end (white) farther from the surgeon is grasped between the tips of the distal phalanges of the left thumb and index finger (tip-to-tip pinch). The tips of the distal phalanges of the thumb and index finger of the right hand grasp the suture end (black) exiting from the wound edge closer to the surgeon. The grasped fingers apply constant tension to the suture ends. The security of this tip-to-tip pinch can be enhanced by grasping the suture ends between the tips of the long fingers, ring fingers, small fingers, and the palm of each hand (grip activity).

The tying of square, slip, and surgeon's knots using manual and instrument-tying techniques are illustrated in Sections VIII-X. The technique of tying slip knots has been included in the manual because it is an excellent method to approximate temporarily the edges of wounds subjected to strong tensions. In fact, a slip knot has greater holding power than either a single-wrap or double-wrap throw.²² Once there is meticulous approximation of wound edges, the slip knot can be converted to a square knot, after which a sufficient number of throws are added to the knot to ensure knot security.

VII. essential elements

DO

1. Pass the surgical needle swaged to a suture through the wound edges in a direction toward you.
2. Construct a two-throw square knot that can be advanced to the wound edge, providing a preview of the ultimate apposition of the wound edges.
3. Approximate the edges of the divided tissue without strangulating the tissue encircled by the suture loop.
4. Once meticulous apposition of the wound edges is achieved, construct a knot that has sufficient number of throws that allow it to fail by breakage rather than by slippage.
5. Position your hands on each side and parallel to the suture loop.

DON'T

1. Pass the surgical needle swaged to a suture through the wound edge in a direction away from you.
2. Construct a secure knot that cannot be advanced to the wound edges.
3. Apply frictional forces (sawing) between the suture "ears" during knot construction that damage the suture and reduce its strength.
4. Add further throws to a knot that has the required number of throws for knot security.
5. Position your hands perpendicular to the suture loop.

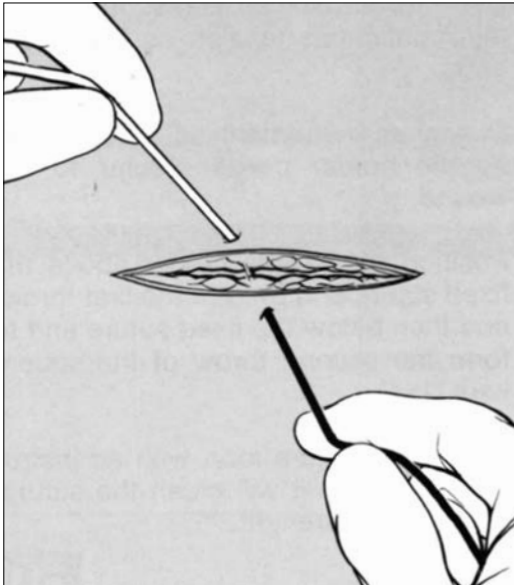
DO

6. Apply opposing forces to the knot "ears" that are equal in magnitude and in a plane parallel to that of the wound surface.
7. After each throw, reverse the position of your hands that apply tension to the suture ends.
8. Apply constant force slowly to the "ears" of each throw of the knot.
9. Use the two-hand tie technique to maintain continuous tension on suture ends.
10. During an instrument tie, position the needle holder parallel to the wound.
11. Position the needle holder above the fixed suture end to form the first and second suture throws of a square (1=1) knot.
12. Clamp only the free end of the suture during the instrument tie.

DON'T

6. Exert unequal levels of tension to the suture ends that convert the knot into a slip knot.
7. Maintain the same position of your hands after each additional throw.
8. Apply a constant force rapidly to the "ears" of each throw of the knot.
9. Use the one-hand tie technique to maintain continuous tension of the suture ends.
10. During an instrument tie, position the needle holder perpendicular to the wound.
11. Position the needle holder above the fixed suture end to form the first throw, and then below the fixed suture end to form the second throw of the square knot (1=1).
12. Clamp the suture loop with an instrument because it will crush the suture, reducing its strength.³⁰⁻³²

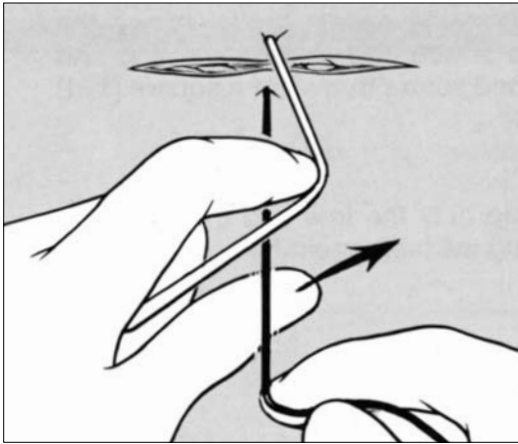
VIII. two-hand tie techniques — SQUARE KNOT (1=1) formation of the first throw



Step 1.

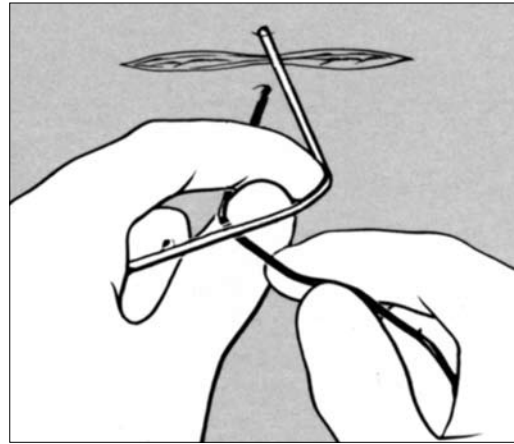
Hold Suture Ends

The suture end exiting from the side of the wound farther from the surgeon is grasped between the tips of the distal phalanges of the left thumb and index finger (tip-to-tip pinch), while the tips of the distal phalanges of the right thumb and index finger grasp the suture end exiting from the closer side of the wound. The grasped fingers apply constant tension to the suture ends. The security of this tip-to-tip pinch of the suture ends can be enhanced by grasping the suture ends between the tips of the long fingers, ring fingers, small fingers and the palm of each hand (grip activity).



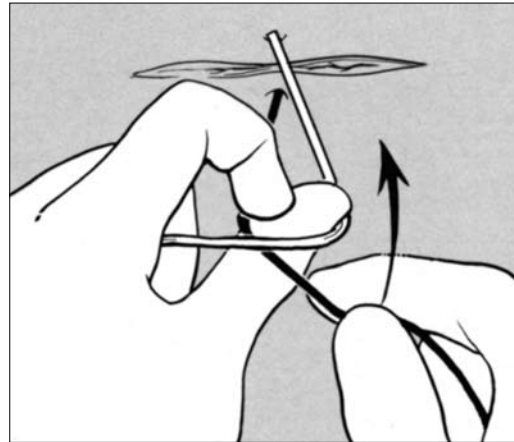
Step 2.
Form the First Suture Loop

The first loop is formed by the tip of the left index finger that passes its suture end over the other suture end held by the right hand. As the tip of the left index finger passes its suture end over the suture end held by the right hand, the left thumb passes under (arrow) the suture end held by the right hand.



Step 3.
**Pass Thumb
Up Through
the Suture
Loop**

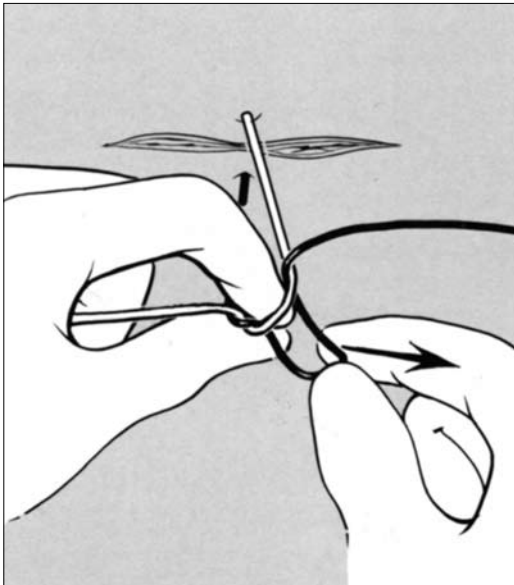
The tip of the left thumb advances up through the suture loop, replacing the tip of the left index finger.



Step 4.
**Pass Free
Suture End
Over the
Suture Loop**

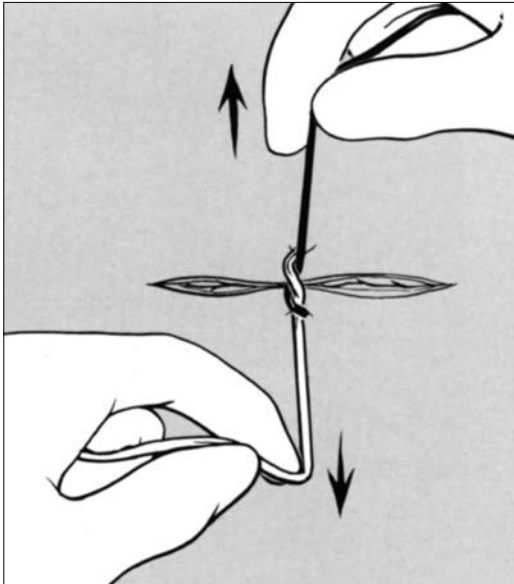
The free suture end, held by the right hand, is passed over (arrow) the suture loop.

VIII. two-hand tie techniques — SQUARE KNOT (1=1) formation of the first throw (cont'd)



Step 5. **Pass Free Suture End Down** **Through the Suture Loop** **to Form Single-Wrap Throw**

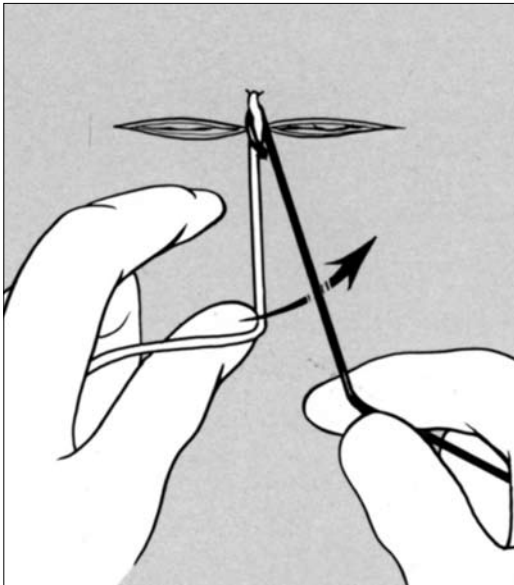
After the suture end is grasped between the tips of the left thumb and index finger, the pinched suture end is passed downward through the suture loop. The right hand releases its free suture end so that it can be passed down through the suture loop. The free suture end is regrasped between the tips of the right thumb and index finger to withdraw (arrow) it through the suture loop to form a single-wrap throw.



Step 6.
Advance First Single-Wrap
Throw to Wound Surface

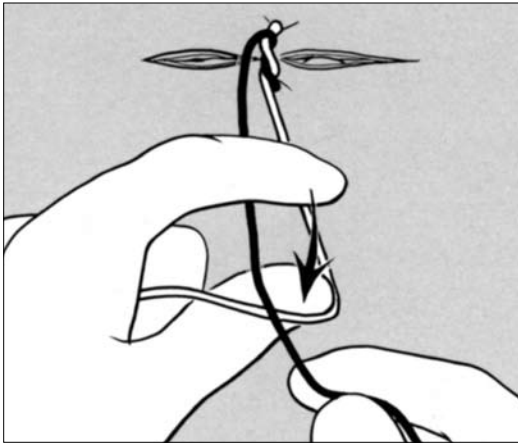
With the suture ends grasped in the palms of the surgeon's hands, the tips of the index fingers and thumbs position the suture ends in a direction (arrows) perpendicular to that of the wound. The surgeon applies constant tension to the suture ends, which advances the first single-wrap throw of the square knot to the surface of the wound. Advancement of the first throw is complete when the divided skin edges of the mid-portion of the wound are approximated.

VIII. two-hand tie techniques — SQUARE KNOT (1=1) formation of the second throw



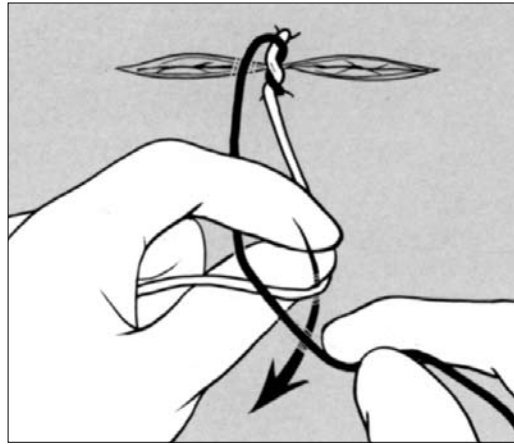
Step 7. Begin Formation of the Second Suture Loop

The dorsum of the tip of the left thumb is passed under its suture end in order to direct it beneath (arrow) the other suture end that is held by the right hand. During formation of the second throw, constant tension is applied to the suture ends to maintain wound approximation.



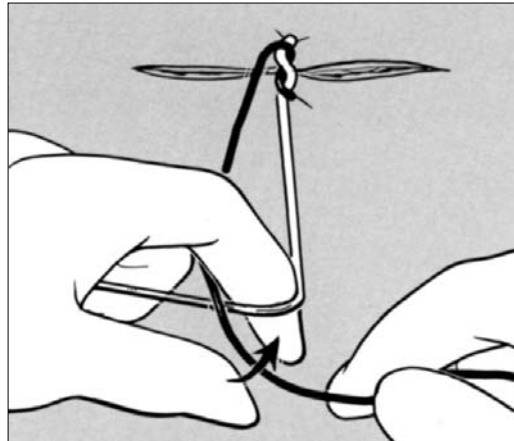
Step 8.
Form the Second Suture Loop

The left thumb advances its suture end beneath the other suture end to form a suture loop. The tip of the left index finger passes down (arrow) to touch the left thumb.



Step 9.
Pass Index Finger Down Through the Suture Loop

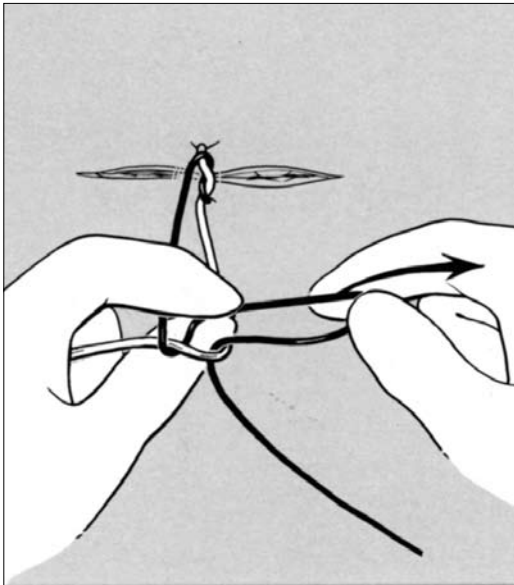
After the tip of the left index finger contacts the tip of the left thumb (tip-to-tip pinch), both are advanced down (arrow) through the suture loop so that only the tip of the left index finger remains in the loop.



Step 10.
Pass Free Suture End Under the Suture Loop

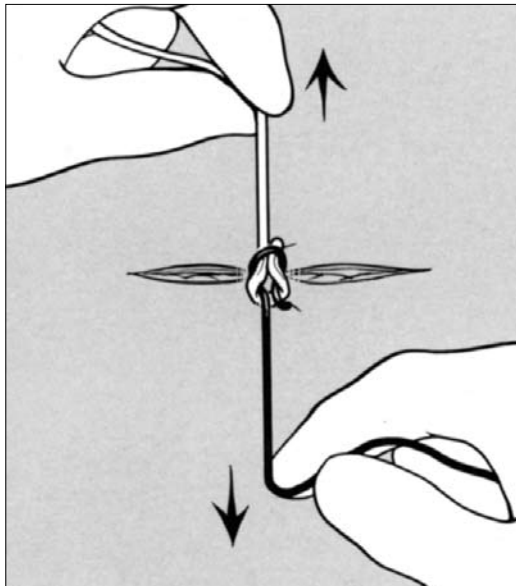
The free suture end held by the right hand is passed under the suture loop to be positioned (arrow) between the tips of the left index finger and thumb.

VIII. two-hand tie techniques — SQUARE KNOT (1=1)
formation of the second throw (cont'd)



Step 11.
Pass Free Suture End
Up Through the Suture
Loop to Form Second,
Single-Wrap Throw

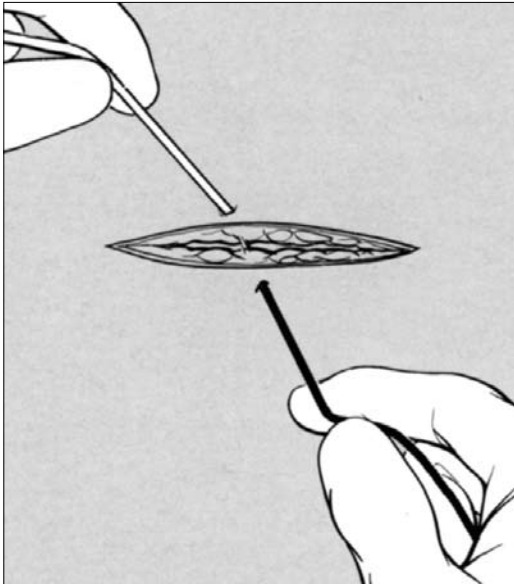
The free suture end grasped between the tips of the left thumb and index finger is advanced upward through the suture loop. The right hand releases its free suture end to allow its passage through the suture loop, after which it regrasps the free suture end to withdraw (arrow) through the suture loop.



Step 12.
Advance Square Knot (1=1)
to Wound Surface

The second throw is advanced and set against the first throw by applying tension in a direction (arrows) perpendicular to that of the wound. Advancement of the second throw is complete when the second throw contacts the first throw to form a square (1=1) knot. Ideally, the surgeon should be able to advance the two-throw, square knot to allow meticulous approximation of the wound edges. Once exact approximation of the wound edges is accomplished, the surgeon will construct a knot with a sufficient number of throws and 3mm cut “ears” so that knot security is determined by knot breakage, rather than by slippage.³

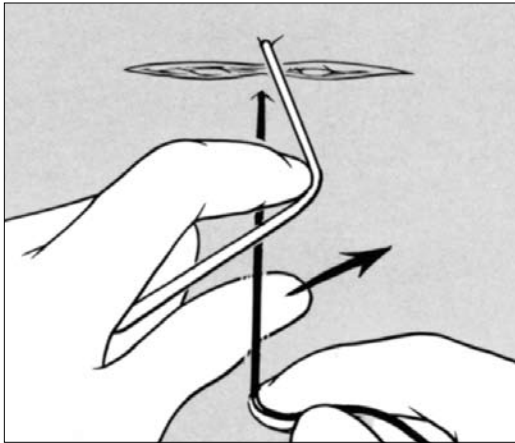
VIII. two-hand tie techniques — SURGEON'S KNOT SQUARE (2=1) formation of the first, double-wrap throw



Step 1.

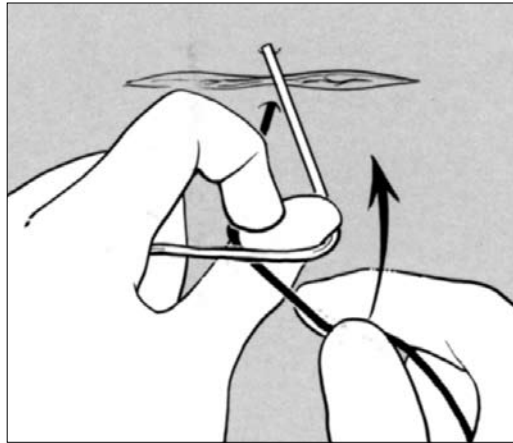
Hold Suture Ends

The suture end exiting from the side of the wound farther from the surgeon is grasped between the tips of the distal phalanges of the left thumb and index finger (tip-to-tip pinch), while the tips of the distal phalanges of the right thumb and index finger grasp the suture end exiting from the closer side of the wound. The grasped fingers apply constant tension to the suture ends. The security of this tip-to-tip pinch of the suture ends can be enhanced by grasping the suture ends between the tips of the long fingers, ring fingers, small fingers and the palm of each hand (grip activity).



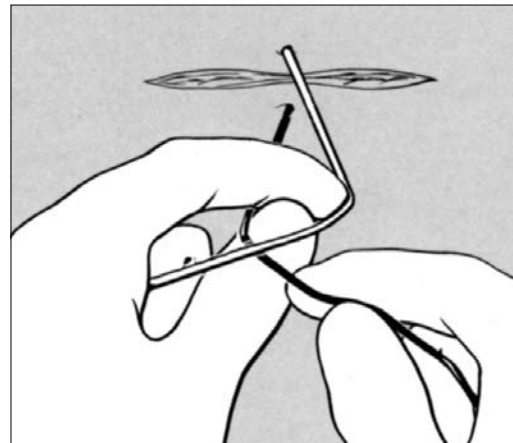
Step 2.
Form the First Suture Loop

The first suture loop is formed by the tip of the left index finger that passes its suture end over the other suture end held by the right hand. As the tip of the left index finger passes its suture end over the suture end held by the right hand, the left thumb passes under (arrow) the suture end held by the right hand.



Step 3.
**Pass Thumb
Up Through
the Suture
Loop**

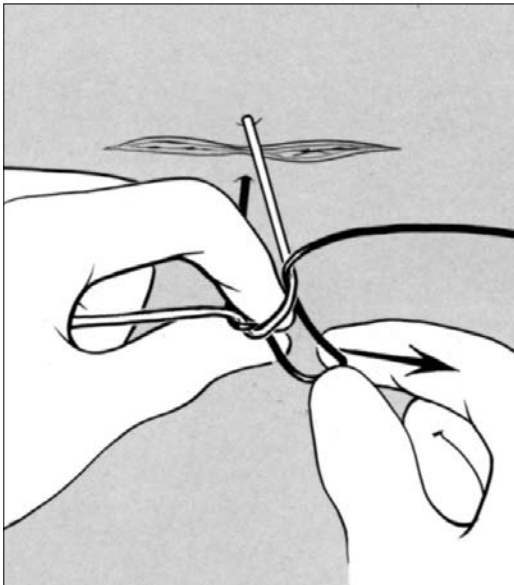
The tip of the left thumb advances up through the suture loop, replacing the tip of the left index finger.



Step 4.
**Pass Free
Suture End
Over the
Suture Loop**

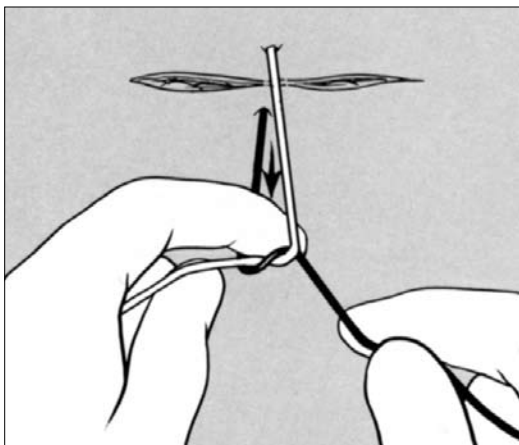
The free suture end, held by the right hand, is passed over (arrow) the suture loop.

VIII. two-hand tie techniques — SURGEON'S KNOT SQUARE (2=1)
formation of the first, double-wrap throw (cont'd)



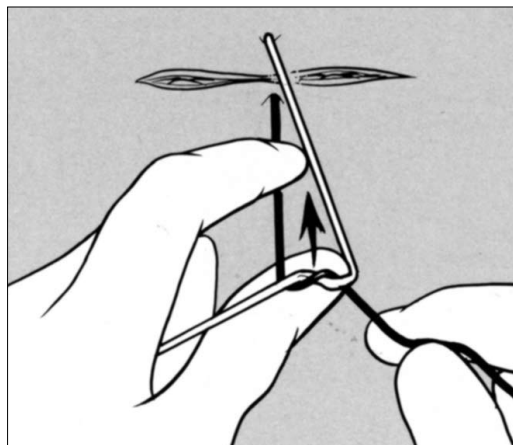
Step 5.
Pass Free Suture End Down
Through the Suture Loop to
Form Single-Wrap Throw

After the free suture end is grasped between the tips of the left thumb and index finger, the pinched suture end is passed downward through the suture loop. The right hand releases its free suture end so that it can be passed through the loop. The tips of the right thumb and index finger regrasp the free suture end to withdraw (arrow) it through the suture loop to form a single-wrap throw.



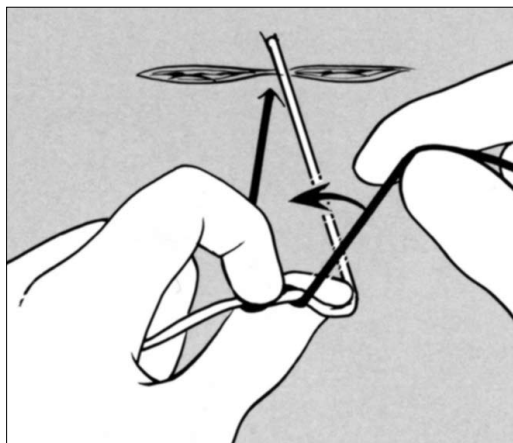
Step 6.
Maintain Suture Loop with Left Index Finger

The rectangular configuration of the suture loop is maintained by keeping the tip of the index finger (arrow) in the suture loop.



Step 7.
**Pass Left Thumb
Up Into the
Suture Loop**

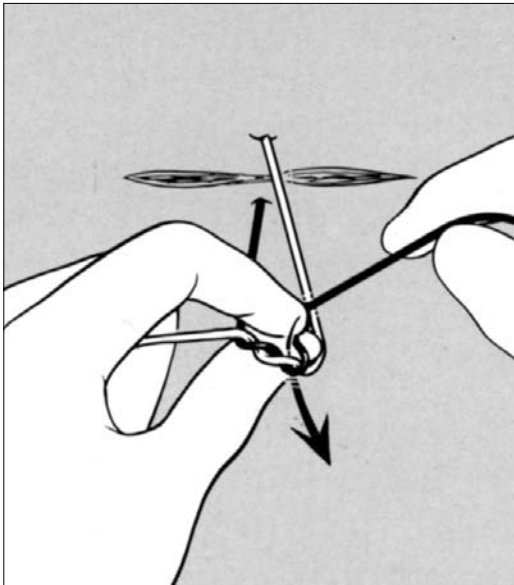
The left thumb passes up (arrow) through the suture loop, replacing the left index finger in preparation for the formation of the double-wrap first throw.



Step 8.
**Pass Free Suture End
Over the Suture Loop**

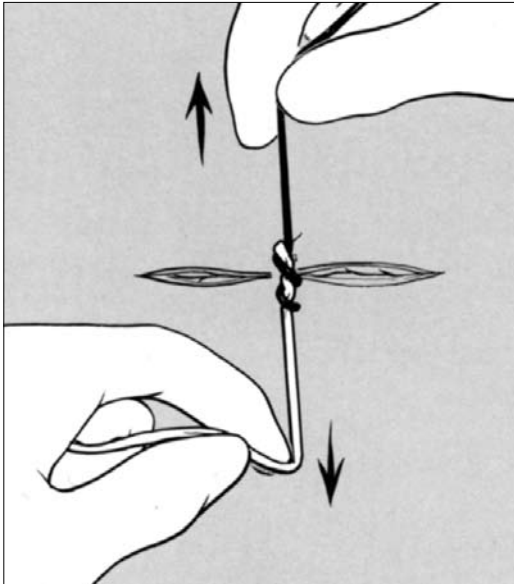
The free suture end held by the right hand is passed over (arrow) the suture loop and grasped between the tips of the left thumb and index finger.

VIII. two-hand tie techniques — SURGEON'S KNOT SQUARE (2=1)
formation of the first, double-wrap throw (cont'd)



Step 9.
Pass Free Suture End
Down Through the
Suture Loop to Form
Double-Wrap,
First Throw

The free suture end grasped between the tips of the left thumb and index finger is passed down (arrow) through the suture loop. The right hand releases its suture end so that it can be withdrawn through the suture loop. As the free suture end passes through the loop, it is regrasped by the right hand to withdraw it through the suture loop.

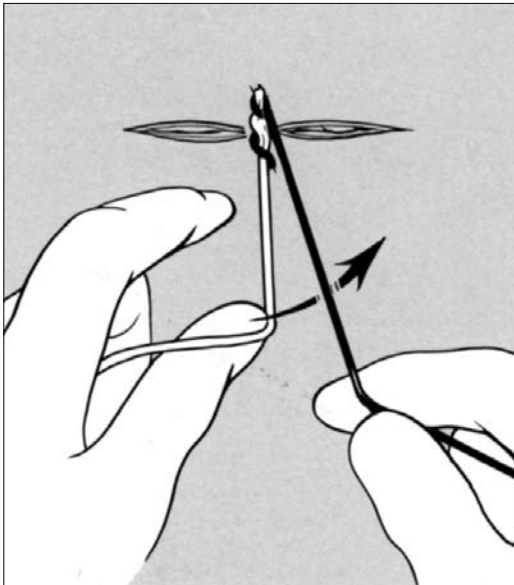


Step 10.
Advance Double-Wrap, First Throw to
Wound Surface

With the suture ends grasped in the palms of the surgeon's hands, the tips of the index fingers and thumbs position the suture ends in a direction (arrows) perpendicular to that of the wound. The surgeon applies constant tension to the suture ends, which advances the double-wrap, first throw of the surgeon's knot square to the surface of the wound.

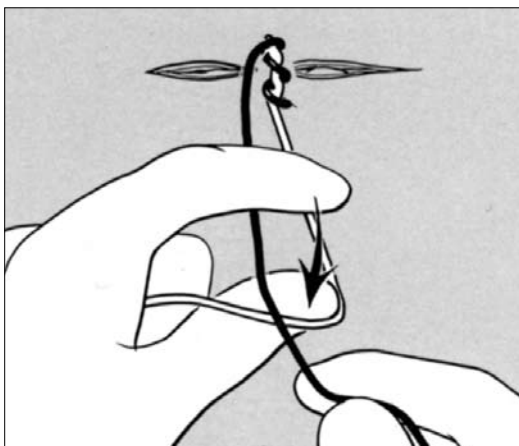
Advancement of the first throw is complete when the divided edges of the mid-portion of the wound are approximated.

VIII. two-hand tie techniques — SURGEON'S KNOT SQUARE (2=1) formation of the second throw



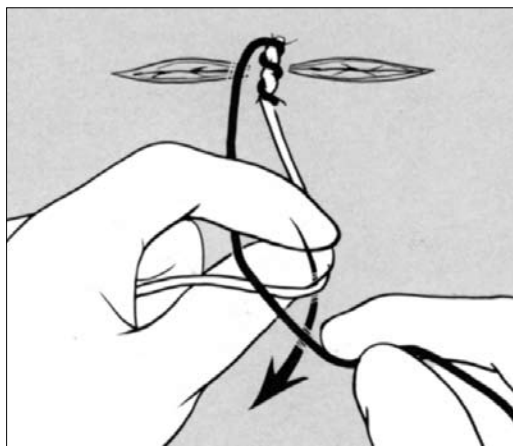
Step 11. **Begin Formation of the** **Second Suture Loop**

The dorsum of the tip of the left thumb is passed under (arrow) its suture end in order to direct it beneath the other suture end that is held by the right hand. During formation of the second throw, constant tension is applied to the suture ends to maintain wound approximation.



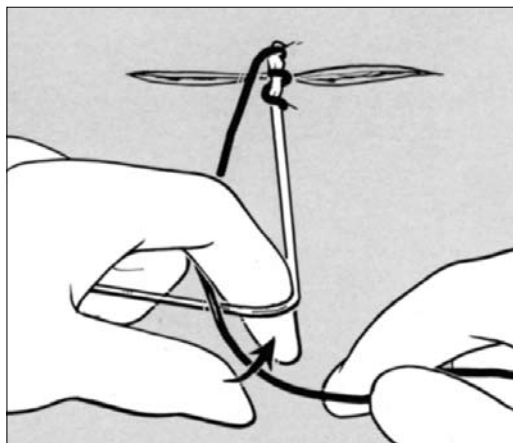
Step 12.
Form the Second Suture Loop

The left thumb advances its suture end beneath the other suture end to form a suture loop. The tip of the left index finger passes down (arrow) to touch the left thumb.



Step 13.
Pass Index Finger Down Through Suture Loop

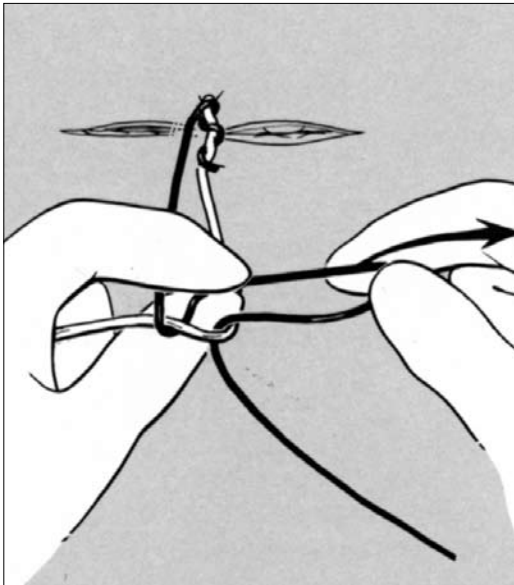
After the tip of the left index finger contacts the tip of the left thumb (tip-to-tip pinch), both are advanced down (arrow) through the suture loop so that only the tip of the left index finger remains in the suture loop.



Step 14.
Pass Free Suture End Under the Suture Loop

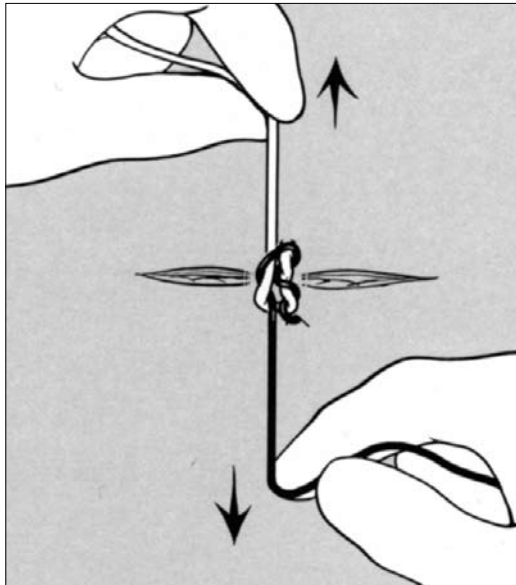
The free suture end held by the right hand is passed under the suture loop to be positioned (arrow) between the tips of the left index finger and thumb.

VIII. two-hand tie techniques — SURGEON'S KNOT SQUARE (2=1)
formation of the second throw (cont'd)



Step 15.
Pass Free Suture End Up
Through the Suture Loop
To Form Single-Wrap Throw

The free suture end grasped between the tips of the left thumb and index finger is advanced upward through the suture loop. The right hand releases its free suture end to allow its passage through the suture loop, after which it regrasps the free suture end to withdraw (arrow) it through the suture loop.



Step 16.
Advance Surgeon's Knot
Square (2=1) to Wound Surface

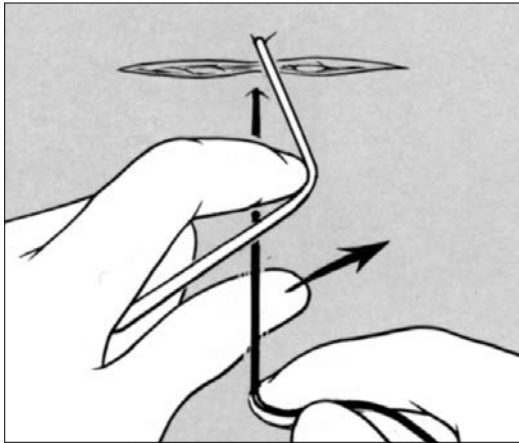
The single-wrap throw is advanced and set against the first double-wrap throw by applying tension in a direction (arrows) perpendicular to that of the wound. Advancement of the second throw is complete when the second throw contacts the first throw to form a surgeon's knot square (2=1). The direction of the tension applied to the suture ends of the first throw is opposite to that exerted on the suture ends of the second throw. Once exact approximation of the wound edges is accomplished, the surgeon will construct a knot with a sufficient number of throws and 3mm cut "ears" so that knot security is determined by knot breakage, rather than by slippage.³

VIII. two-hand tie techniques — SLIP KNOT (S=S) formation of the first throw



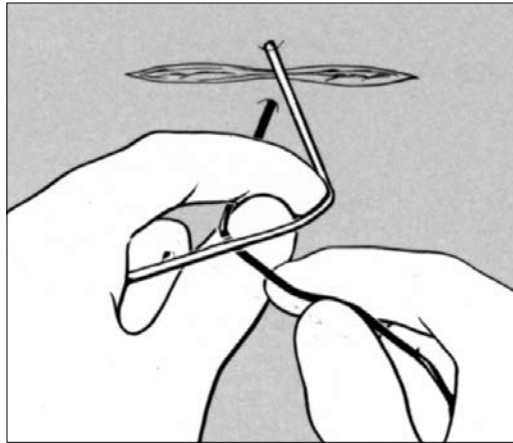
Step 1. **Hold Suture Ends**

The suture end exiting from the side of the wound farther from the surgeon is grasped between the tips of the distal phalanges of the left thumb and index finger (tip-to-tip pinch), while the tips of the distal phalanges of the right thumb and index finger grasp the suture end exiting from the closer side of the wound. The grasped fingers apply constant tension to the suture ends. The security of this tip-to-tip pinch of the suture ends can be enhanced by grasping the suture ends between the tips of the long fingers, ring fingers, small fingers and the palm of each hand (grip activity).



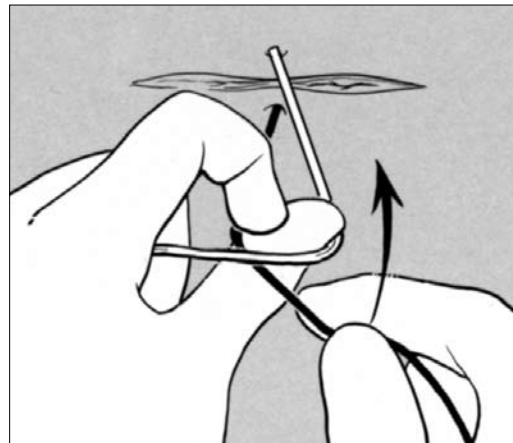
Step 2.
Form the First Suture Loop

The first suture loop is formed by the tip of the left index finger that passes its suture end over the other suture end held by the right hand. As the tip of the left index finger passes its suture end over the suture end held by the right hand, the left thumb passes under (arrow) the suture end held by the right hand.



Step 3.
Pass Thumb Up Through the Suture Loop

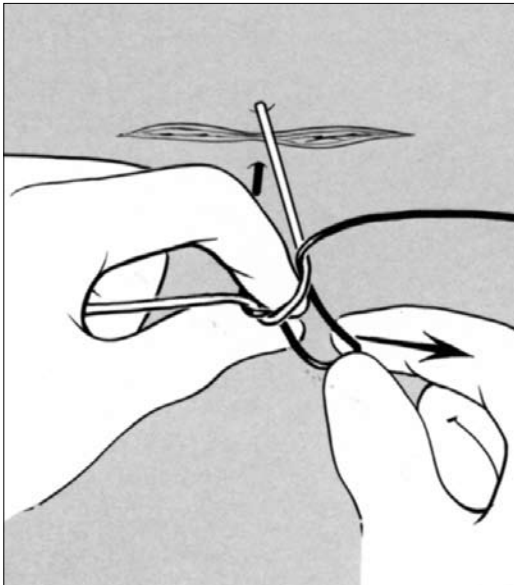
The tip of the left thumb advances up through the suture loop, replacing the tip of the left index finger.



Step 4.
Pass Free Suture End Over the Suture Loop

The free suture end, held by the right hand, is passed over (arrow) the suture loop.

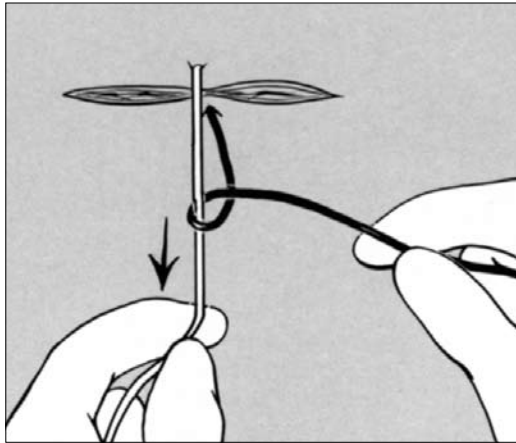
VIII. two-hand tie techniques — SLIP KNOT (S=S) formation of the first throw (cont'd)



Step 5.

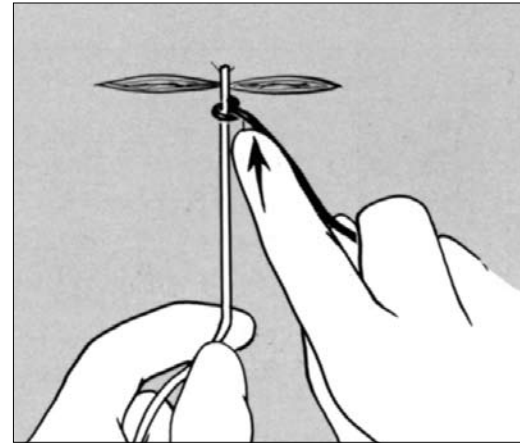
Pass Free Suture End Down Through the Suture Loop

After the suture end is grasped between the tips of the left thumb and index finger, the pinched suture end is passed downward through the suture loop. The right hand releases its free suture end so that it can be passed down through the suture loop. The free suture end is regrasped between the tips of the right thumb and index finger to withdraw (arrow) it through the suture loop.



Step 6.
Apply Tension to the Straight, Taut Suture End

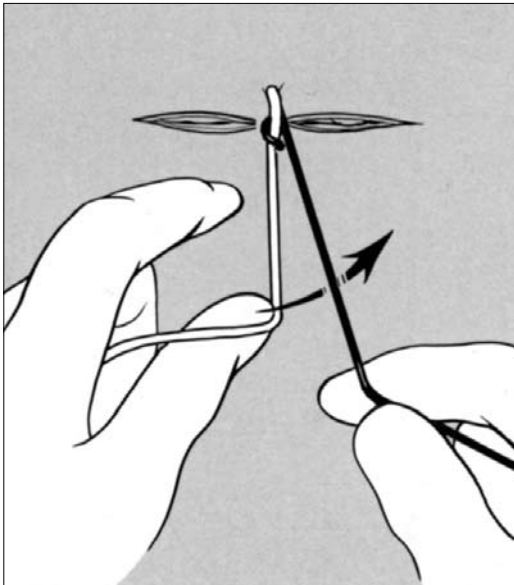
The first throw of the slip knot is completed by first applying tension (arrow) to the suture held by the left hand causing the suture end to be straight and taut. The suture end held by the right hand forms a loop around the straight, taut suture held by the left hand.



Step 7.
Advance First Throw to Wound

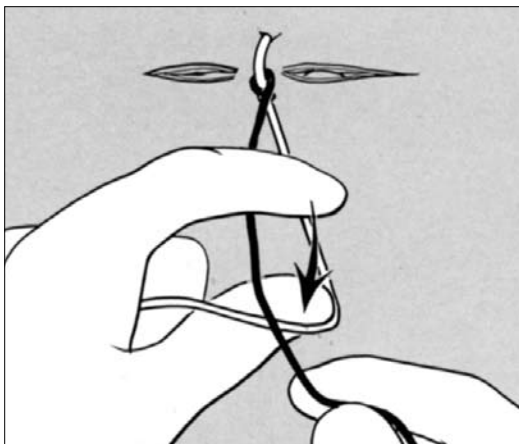
The tip of the right index finger slides (arrow) the loop along the straight, taut suture end held by the left hand until the loop contacts the wound. Advancement of the first throw is complete when the divided skin edges of the mid-portion of the wound are approximated.

VIII. two-hand tie techniques — SLIP KNOT (S=S) formation of the second throw



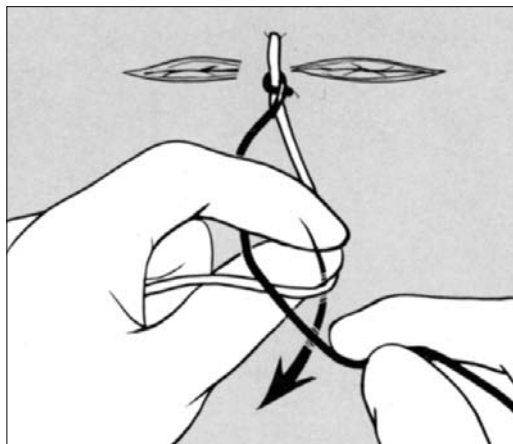
Step 8. **Begin Formation of** **Second Suture Loop**

The dorsum of the tip of the left thumb is passed under its suture end in order to direct it beneath (arrow) the other suture end that is held by the right hand. During formation of the second throw, constant tension is applied to the suture ends to maintain wound approximation.



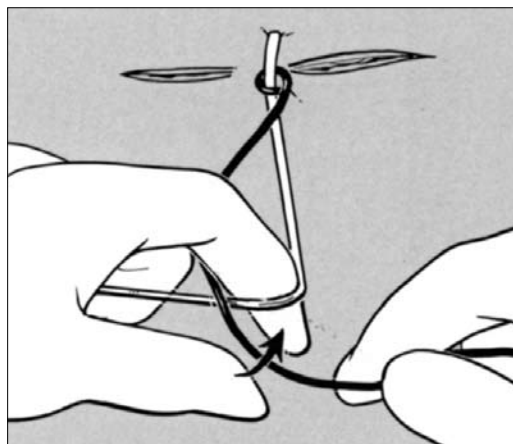
Step 9.
Form the Second Suture Loop

The left thumb advances its suture end beneath the other suture end to form a suture loop. The tip of the left index finger passes down (arrow) to touch the left thumb.



Step 10.
Pass Index Finger Down Through the Suture Loop

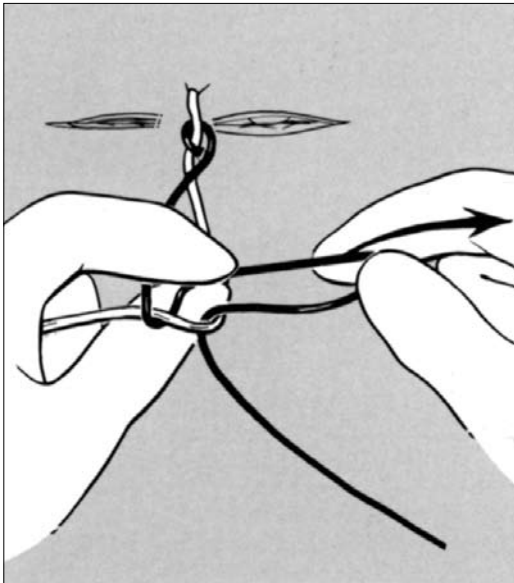
After the tip of the left index finger contacts the tip of the left thumb (tip-to-tip pinch), both are advanced down (arrow) through the suture loop so that only the tip of the left index finger remains in the suture loop.



Step 11.
Pass Free Suture End Under the Suture Loop

The free suture end held by the right hand is passed under the suture loop to be positioned (arrow) between the tips of the left index finger and thumb.

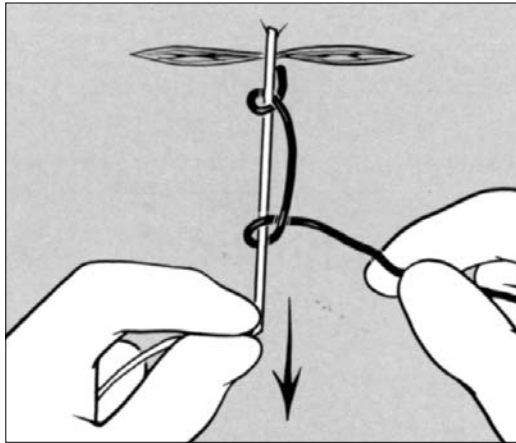
VIII. two-hand tie techniques — SLIP KNOT (S=S)
formation of the second throw (cont'd)



Step 12.

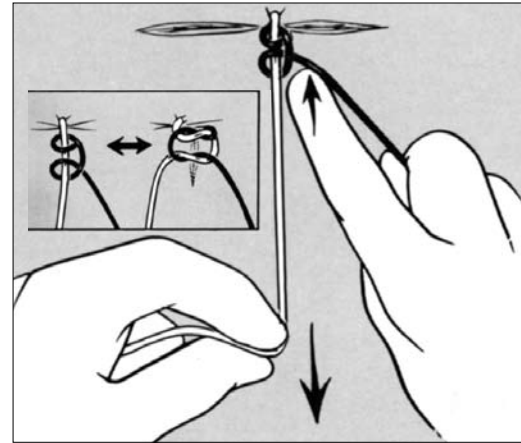
Pass Free Suture End Up Through the Suture Loop

The free suture end grasped between the tips of the left thumb and index finger is advanced upward through the suture loop. The right hand releases its free suture end to allow its passage through the suture loop, after which it regrips the free suture end to withdraw (arrow) it through the suture loop.



Step 13.
Apply Tension to the Straight, Taut Suture End to Form Second Throw

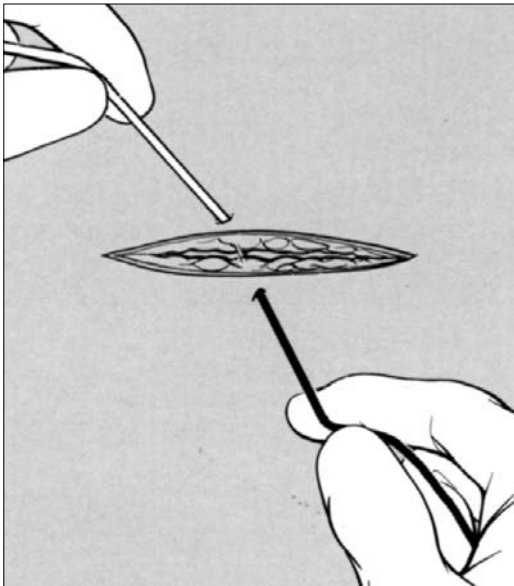
The tension applied (arrow) to the suture end held by the left hand causes this suture end to become straight and taut. The suture end held by the right hand forms a second loop around the straight, taut suture end held by the left hand.



Step 14.
Advance Slip Knot (S=S) to Wound Surface

The tip of the right index finger slides (arrow) this second throw against the first throw, completing the slip knot (S=S), while the left hand maintains tension (arrow) on its suture end. The slip knot will become a square knot by applying tension to the suture end held by the right hand. (Insert) The square knot can be converted to a slip knot by applying tension primarily to one suture end.

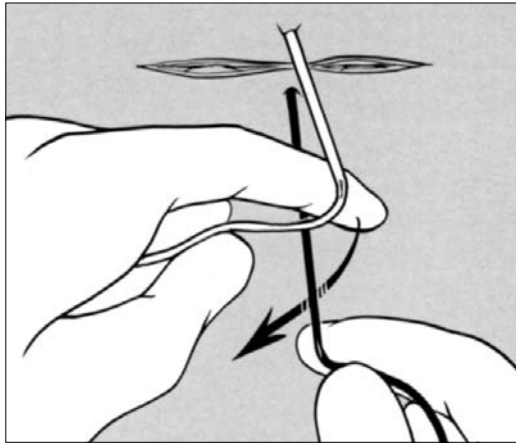
IX. one-hand tie technique — SQUARE KNOT (1=1) formation of the first throw



Step 1.

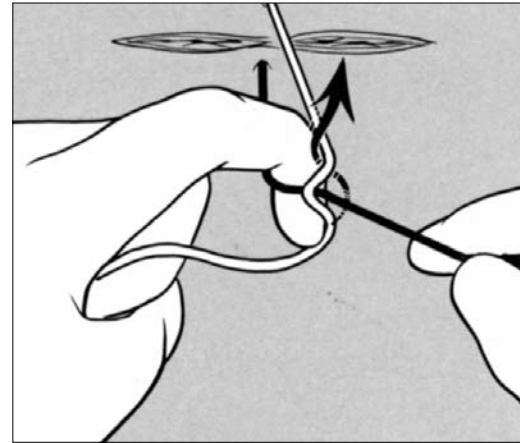
Hold Suture Ends

The suture end exiting from the side of the wound farther from the surgeon is grasped between the tips of the distal phalanges of the left thumb and index finger (tip-to-tip pinch), while the tips of the distal phalanges of the right thumb and index finger grasp the suture end exiting from the closer side of the wound. The grasped fingers apply constant tension to the suture ends. The security of this tip-to-tip pinch of the suture ends can be enhanced by grasping the suture ends between the tips of the long fingers, ring fingers, small fingers and the palm of each hand (grip activity).



Step 2.
Form the First Suture Loop

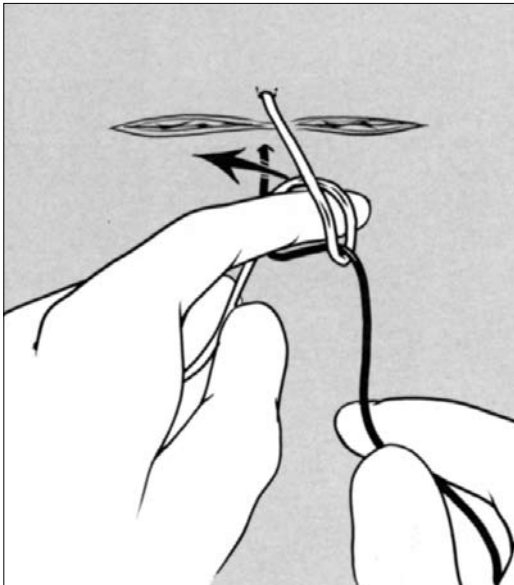
The first throw of the square knot is initiated by the tip of the left index finger that passes its free suture end over the fixed suture end held between the tips of the right index finger and thumb. The tip of the left index finger begins to flex around (arrow) the fixed suture end held by the right hand. Note that the left hand forms the suture loop and passes the free suture end through the suture loop. Consequently, knot construction can be safely accomplished without detaching the needle from the fixed suture end.



Step 3.
**Pass Index Finger Down into
The Suture Loop**

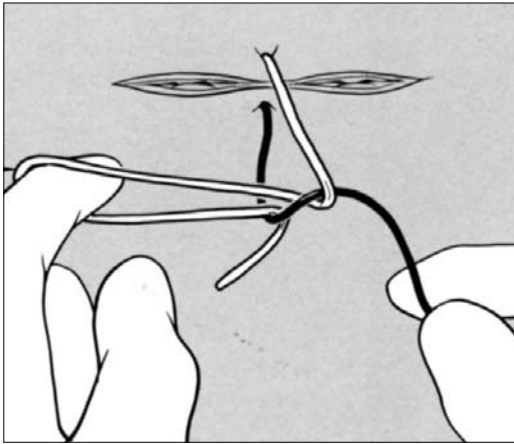
As the index finger passes into the suture loop, flexion of the tip of the left index finger continues until the dorsal surface of its distal phalanx contacts the free suture end held by the left hand. After the free suture end rests on the dorsal surface of the tip of the left index finger, extension of the finger will begin withdrawal (arrow) of the free suture end up through the suture loop.

IX. one-hand tie technique — SQUARE KNOT (1=1)
formation of the first throw (cont'd)



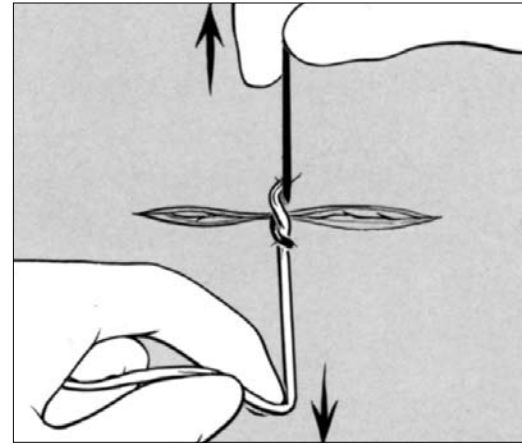
Step 4.
Begin Withdrawal of Free Suture End Up
Through the Suture Loop

Extension of the distal phalanx of the left index finger brings the suture end held by the left hand upward (arrow) through the loop.



Step 5.
**Pass Free Suture End Up Through
the Suture Loop**

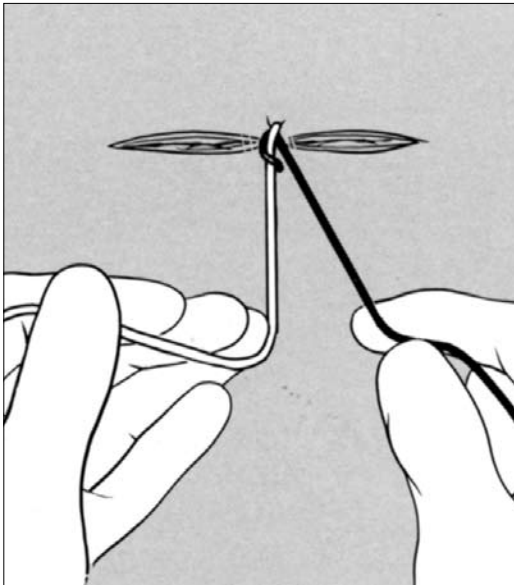
For the left index finger to bring the entire suture end up (arrow) through the loop, the left hand must release its grip of the suture. During this interval, tension cannot be maintained continually on the first throw, allowing the first-throw suture loop to widen, with subsequent partial separation of the wound edges.



Step 6.
**Advance First Single-Wrap Throw
to Wound Surface**

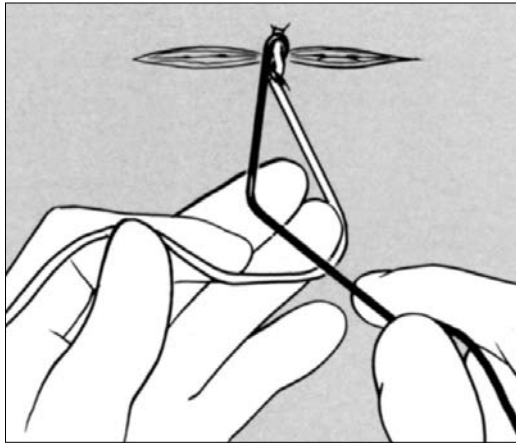
With the suture ends grasped in the palms of the surgeon's hands, the tips of the thumbs and index fingers position the suture ends in a direction (arrows) perpendicular to that of the wound. The surgeon applies constant tension to the suture ends, which advances the first, single-wrap throw of the square knot to the surface of the wound. Advancement of the first throw is complete when the divided skin edges of the mid-portion of the wound are approximated.

IX. one-hand tie technique — SQUARE KNOT (1=1) formation of the second throw



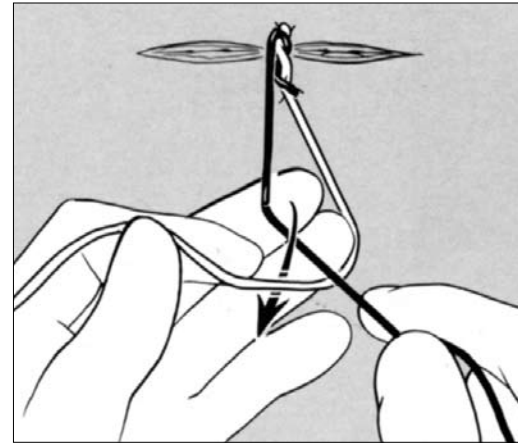
Step 7. **Begin Formation of the** **Second Suture Loop**

While grasping the suture end exiting from the farther side of the wound between the tips of the left thumb and index finger, the surgeon supinates the left wrist so that the free suture end is positioned over the tips of the long, ring and small fingers.



Step 8.
Form the Second Suture Loop

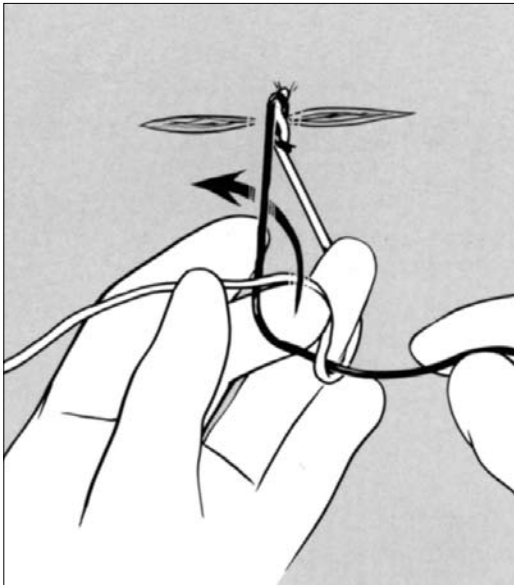
With continued supination of the wrist, the tips of the left long and ring fingers advance their free suture end under the suture end held by the right hand to form a suture loop.



Step 9.
Flex Long Finger Toward the Free Suture End

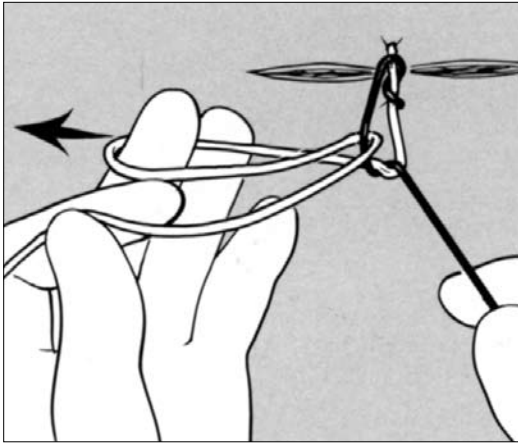
Continued flexion (arrow) of the distal phalanx of the left long finger allows the tip of the finger to pass beneath the free suture end held between the tips of the left thumb and index finger.

IX. one-hand tie technique — SQUARE KNOT (1=1) formation of the second throw (cont'd)



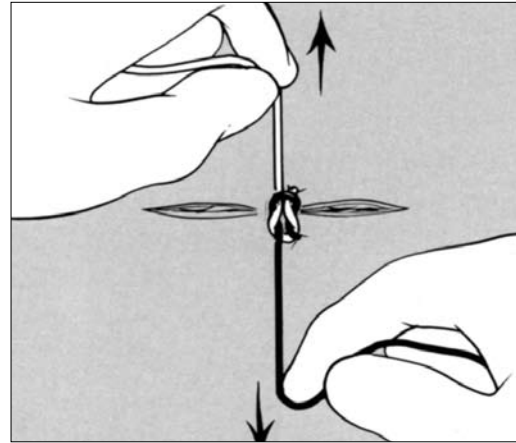
Step 10. **Begin Withdrawal of the** **Free Suture End Down Through** **the Suture Loop**

Once the dorsum of the distal phalanx of the left long finger is beneath the free suture end held between the tips of the left thumb and index finger, extension of the distal phalanx of the long finger begins to withdraw (arrow) the suture end down through the loop. For the left long finger to withdraw the entire free suture end down through the loop, the left thumb and index finger must release their grip of the suture. During this interval, tension cannot be maintained continually on the first throw, allowing the first-throw, suture loop to widen with subsequent partial separation of the wound edges.



Step 11.
Complete Withdrawal of the Free Suture End Down Through the Suture Loop to Form Second, Single-Wrap Throw

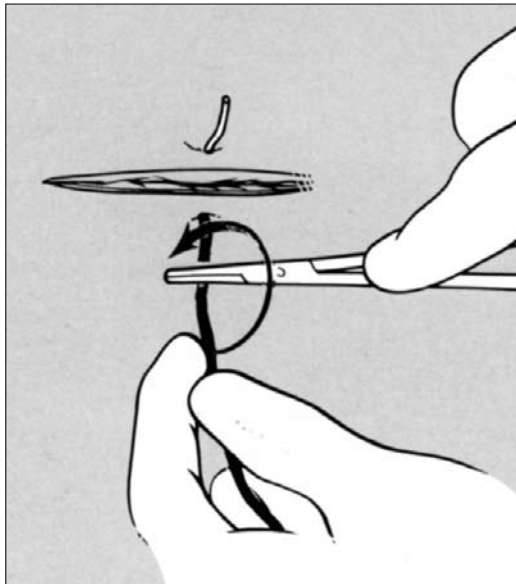
During withdrawal (arrow) of the free suture end through the loop, it is held loosely between the tips of the left long and ring fingers. This loose grasp (key pinch) between the ulnar side of the distal phalanx of the left long finger and the radial side of the distal phalanx of the left ring finger does not allow constant tension to be maintained on this suture end. For the left long and ring fingers to withdraw (arrow) the entire suture end through the loop, the tips of the left thumb and index finger must release the suture.



Step 12.
Advance Square Knot (1=1) to Wound Surface

The second throw is advanced and set against the first throw by applying tension in a direction (arrows) perpendicular to that of the wound. Advancement of the second throw is complete when the second throw contacts the first throw to form a square (1=1) knot. Ideally, the surgeon should be able to advance the two-throw, square knot to allow meticulous approximation of the wound edges. Once exact approximation of the wound edges is accomplished, the surgeon will construct a knot with a sufficient number of throws and 3mm cut “ears” so that knot security is determined by knot breakage, rather than by slippage.³

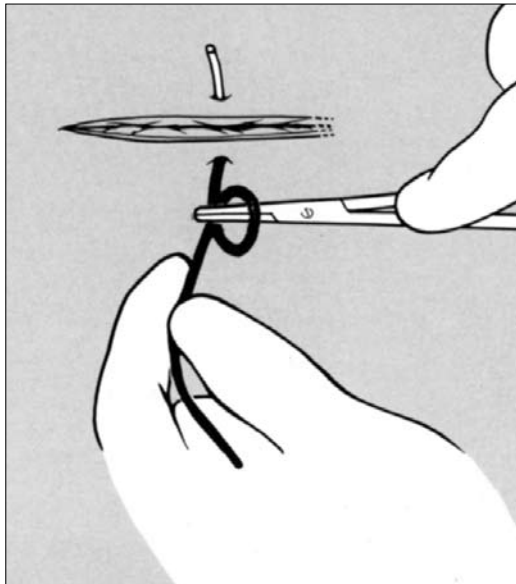
X. instrument-tie technique — SQUARE KNOT (1=1) formation of the first throw (cont'd)



Step 1. **Position the Needle Holder**

The instrument tie is performed with a needle holder held in the surgeon's right hand.

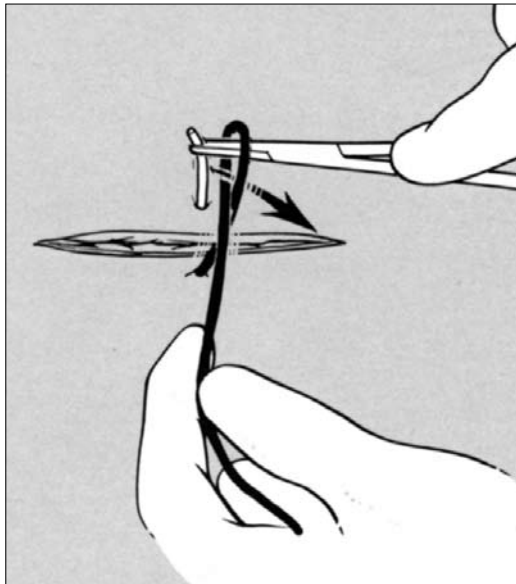
The left hand holds the fixed suture end between the tips of the thumb and index finger. The needle holder is positioned perpendicular to and above the fixed suture end. By keeping the length of the free suture end relatively short (<2 cm), it is easy to form (arrow) suture loops as well as to save suture material. Because the needle holder passes the free suture end through the suture loop, knot construction can be safely accomplished without detaching the needle from the fixed suture end.



Step 2.
Form the First Suture Loop

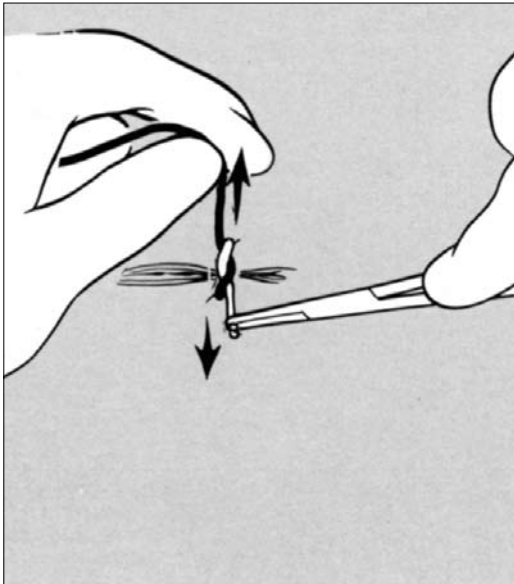
The fixed suture end held by the left hand is wrapped over and around the needle holder jaws to form the first suture loop. (If the suture is wrapped twice around the needle holder jaws, the first, double-wrap throw of the surgeon's knot square will be formed. A double-wrap, first throw displays a greater resistance to slippage than a single-wrap throw, accounting for its frequent use in instrument ties in wounds subjected to strong, static skin tensions).

X. instrument-tie technique — SQUARE KNOT (1=1)
formation of the first throw (cont'd)



Step 3.
Clamp Free Suture End
And Withdraw it Through
the Suture Loop to Form
the First, Single-Wrap
Throw

The tips of the needle holder jaws grasp the suture end and withdraw (arrow) it through the first suture loop. The resulting first throw will have a figure “8” shape.

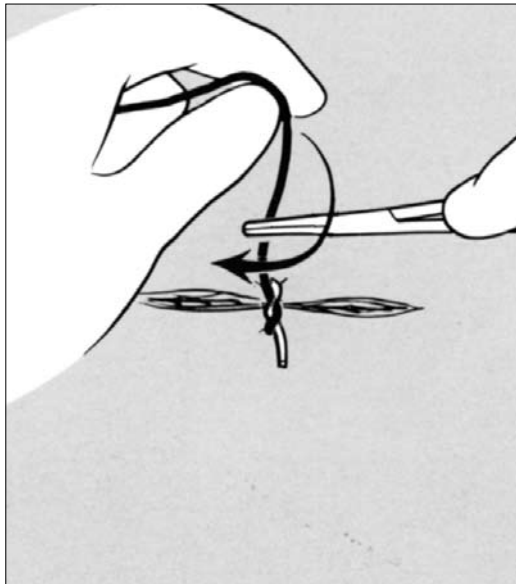


Step 4.

Advance the First Single-Wrap Throw to Wound Surface

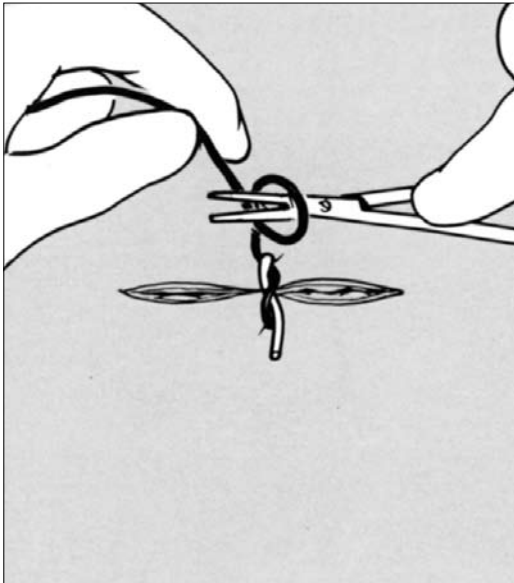
The figure “8” shape throw will be converted into a rectangular-shaped throw by reversing the direction of the hand movement. The left hand moves away from the surgeon, while the needle holder held in the right hand advances toward the surgeon. This single-wrap throw is advanced to the wound surface by applying tension in a direction (arrows) that is perpendicular to that of the wound. Once the first throw of the square knot contacts the skin, the edges of the mid-portion of the wound are approximated.

X. instrument-tie technique — SQUARE KNOT (1=1)
formation of the second throw



Step 5.
Position the Needle Holder

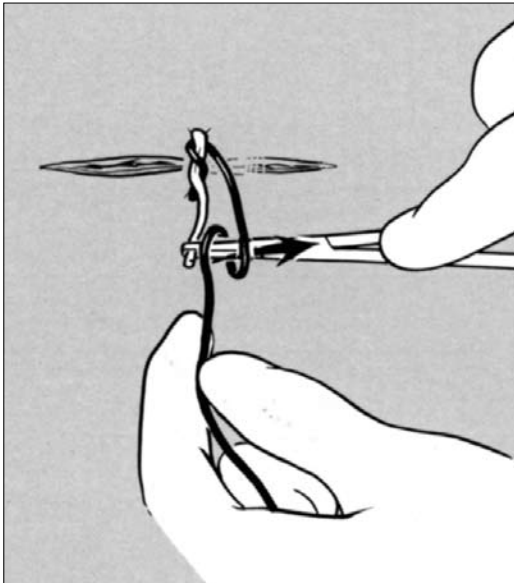
The needle holder releases the free suture end. The right hand holding the needle holder moves away from the surgeon to be positioned perpendicular to and above the fixed suture end. A second throw will be formed by the left hand as it wraps the fixed suture end over and around (arrow) the needle holder jaws. If the surgeon were to place the needle holder beneath the fixed suture end, the ultimate knot construction would be a granny knot (1x1).



Step 6.
Form the Second Suture Loop

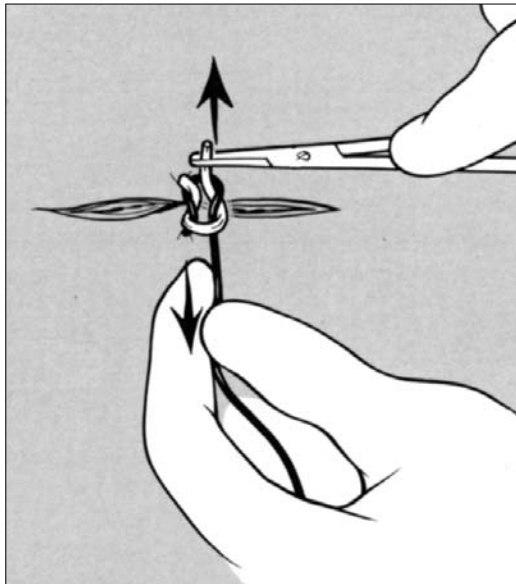
The fixed suture end held by the left hand is wrapped over and around the needle holder to form the second suture loop. With the suture wrapped around the needle holder jaws, the needle holder is moved to grasp the free suture end, after which it is withdrawn through the suture loop.

X. instrument-tie technique — SQUARE KNOT (1=1)
formation of the second throw (cont'd)



Step 7.
Clamp Suture End and Withdraw it Through
the Suture Loop to Form the Second,
Single-Wrap Throw

The tips of the needle holder jaws grasp the free suture end and withdraw (arrow) it through the second suture loop. By withdrawing the free suture end through the loop, a rectangular-shaped second throw is formed. The surgeon will apply tension to the suture ends in a direction perpendicular to that of the wound.



Step 8.
Advance Square Knot (1=1)
to Wound Surface

The second throw is advanced and set against the first throw by applying tension to the suture ends in a direction (arrows) perpendicular to that of the wound. Advancement of the second throw is complete when the second throw contacts the first throw and forms a square knot. Ideally, the surgeon should be able to advance the two-throw, square knot (1=1) to allow meticulous approximation of the wound edges. Once exact approximation of the wound edges is accomplished, the surgeon will construct a knot using this instrument technique, with a sufficient number of throws and 3mm cut “ears” so that knot security is determined by knot breakage, rather than by slippage.³

XI. selection of suture and needle products

On the basis of the largest multicentric evaluation of suture and needle products reported, suture and needle products made by Covidien (formerly Tyco Healthcare Group LP, Norwalk, CT) received an extremely high acceptability rating by the surgeons.³³ In this multicentric evaluation of suture and needle products conducted by Consortia, Inc. (Rolling Meadows, IL), 42 shareholder hospitals enrolled 1913 surgeons to participate in this nonexperimental observational study of the clinical performance of 25,545 suture and needle products. Performance characteristics of the suture and needle products produced by Covidien were judged by clinically acceptable and nonacceptable ratings. Of these suture and needle products, the surgeons found that 98.1% had clinical acceptable ratings for the 25,545 suture and needle products evaluated. While the study coordinated by Consortia Inc. provides important guidelines for judging the clinical acceptability of suture and needle products in a hospital setting, this rigorous suture and needle performance evaluation confirms the high level of performance of the suture and needle products made by Covidien.

XII. full text scientific articles available at www.covidien.com/syneture

A complete copy of this study can be found at www.covidien.com/syneture.

- A. Rodeheaver GT, Shimer AL, Boyd LM, Drake DB, Edlich RF.
An innovative absorbable coating for the polybutester suture.
J Long Term Eff Med Implants 2001;11(1-2):41-54.
- B. Szarmach RR, Livingston J, Rodeheaver GT, Thacker JG, Edlich RF.
An innovative surgical suture and needle evaluation and selection program.
J Long Term Eff Med Implants 2002;12(4):211-229.
- C. Szarmach RR, Livingston J, Edlich RE. An expanded surgical suture and
needle evaluation and selection program by a healthcare resource management
group purchasing organization. J Long Term Eff Med Implants 2003;13(3):155-170.
- D. Drake DB, Rodeheaver PE, Edlich RF, Rodeheaver GT. Experimental studies in
swine for measurement of suture extrusion. J Long Term Eff Med Implants
2004;14(3):251-259.
- E. Pineros-Fernandez A, Drake DB, Rodeheaver PA, Moody DL, Edlich RF
Rodeheaver GT. Caprosyn™, another major advance in synthetic monofilament
absorbable suture. J Long Term Eff Med Implants 2005;14(5):359-368.

XIII. references

1. Graumont R, Hensel J: Encyclopedia of knots and fancy rope work. Cornell Maritime Press, N.Y., 1943, pp 3-10.
2. Haxton H: The influence of suture materials and methods on the healing of abdominal wounds. *Br J Surg* 1965;52:372-375.
3. Thacker JG, Rodeheaver G, Kurtz L, Edgerton MT, Edlich RF. Mechanical Performance of sutures in surgery *Am J Surg* 1977;133:713-715.
4. Trimbos JB. Security of various knots commonly used in surgical practice. *Obstet Gynecol* 1984;64:274-280.
5. Edlich RF, Wind TC, Hill LG, Thacker JG, McGregor W. Reducing accidental injuries during surgery. *J Long Term Eff Implant* 2003;13(1):1-10.
6. Edlich RF, Panek PH, Rodeheaver GT, Turnbull VG, Kurtz LD, Edgerton MT. Physical and chemical configuration of sutures in the development of surgical infection. *Ann Surg* 1973 Jun;177(6):679-688.
7. Postlethwait RW. Long-term comparative study of non-absorbable sutures. *Ann Surg* 1970;171:892-898.
8. Rodeheaver GT, Nesbit WS, Edlich RF. Novafil, a dynamic suture for wound closure. *Ann Surg* 1986;204:193-199.
9. Trimbos JB, Smeets M, Verdel M, Hermans J. Cosmetic result of lower midline laparotomy wounds: polybutester and nylon skin suture in a randomized clinical trial. *Obstet Gynecol* 1993;82(3):390-393.

10. Pinheiro AL, de Castro JF, Thiers FA, Cavalcanti ET, Rego TI, de Quevedo AS, Lins AJ, Aca CR. Using Novafil: would it make suturing easier? *Braz Dent J* 1997;8(1):21-25.
11. Rodeheaver GT, Shimer AL, Boyd LM, Drake DB, Edlich RF. An innovative absorbable coating for the polybutester suture. *J Long Term Effects Med Implants* 2001;11 (1 & 2):41-54.
12. Salthouse TN, Williams JA, Willigan DA. Relationship of cellular enzyme activity to catgut and collagen suture absorption. *Surg Gynecol Obstet* 1981;129:691-696.
13. Rodeheaver GT, Thacker JG, Edlich RF. Mechanical performance of polyglycolic acid and polyglactin 910 synthetic absorbable sutures. *Surg Gynecol Obstet* 1981;153:835-841.
14. Faulkner BC, Gear AJ, Hellewell TB, Mazzaresse PM, Watkins FH, Edlich RF. Biomechanical performance of a braided absorbable suture. *J Long Term Effects Med Implants* 1996;6:169-179.
15. Drake DB, Rodeheaver PE, Edlich RF, Rodeheaver GT. Experimental studies in swine for measurement of suture extrusion. *J Long Term Effects Med Implants* 2004;14(3):251-259.
16. Katz AR, Mukherjee DP, Kaganov AL, Gordon S. A new synthetic monofilament absorbable suture made from polytrimethylene carbonate. *Surg Gynecol Obstet* 1985;161:213-222.
17. Rodeheaver GT, Beltran KA, Green CW, Faulkner BC, Stiles BM, Stanimir GW, Traeland H, Fried GM, Brown HC, Edlich RF. Biomechanical and clinical performance of a new synthetic monofilament suture. *J Long Term Effects Med Implants* 1996;6:181-196.

XIII. references (cont'd)

18. Pineros-Fernandez A, Drake DB, Rodeheaver PA, Moody DL, Edlich RF Rodeheaver GT. CAPROSYN™, another major advance in synthetic monofilament absorbable suture. *J Long Term Eff Med Implants* 2005;14(5):359-368.
19. Thacker JG, Rodeheaver GT, Moore JW, Kauzlarich JJ, Kurtz L, Edgerton MT, Edlich RF: Mechanical performance of surgical sutures. *Am J Surg* 1975;130:374-380.
20. Taylor FW: Surgical knots. *Ann Surg* 1938;107:458-468.
21. Tera H, Åberg C. Tensile strength of twelve types of knot employed in surgery, using different suture materials. *Acta Chir Scand* 1976;142:1-7.
22. Annuziata CC, Drake DB, Woods JA, Gear AJL, Rodeheaver GT, Edlich RF. Technical considerations in knot construction. Part I. Continuous percutaneous and dermal suture closure. *J Emerg Med* 1997; 15: 351-356.
23. Rodeheaver GT, Borzelleca DC, Thacker JG, Edlich RF. Unique performance characteristics of Novafil®. *Surg Gynecol Obstet* 1987;142:230-360.
24. Zimmer CA, Thacker JG, Powell DM, Bellian KT, Becker DG, Rodeheaver GT, Edlich RF. Influence of knot configuration and tying technique on the mechanical performance of sutures. *J Emerg Med* 1991;9:107-113.
25. Holmlund DE. Knot properties of surgical suture materials. A model study. *Acta Chir Scand* 1974;140:355-362.

26. Howes EL, Harvey SC. The strength of the healing wound in relation to the holding strength of the catgut suture. *N Engl J Med* 1929; 200:1285-1290.
27. Tera H, Åberg C. Tissue strength of the healing wound in relation to the holding strength of the catgut suture. *N Engl J Med* 1929;200:1285-1290.
28. Åberg C. Change in strength of aponeurotic tissue enclosed in the suture during the initial healing period. An Experimental investigation in rabbits. *Acta Chir Scand* 1976;142:429-432.
29. Nichols WK, Stanton M, Silver D, Keitzer WF. Anastomotic aneurysms following lower extremity revascularization. *Surgery* 1980;88:366-374.
30. Stamp CV, McGregor W, Rodeheaver GT, Thacker JG, Towler MA, Edlich RF. Surgical needle holder damage to sutures. *Am Surg* 1988;54:300-306.
31. Abidin MR, Towler MA, Thacker JG, Nochimson GD, McGregor W, Edlich RF. New atraumatic rounded-edge surgical needle holder jaws. *Am J Surg* 1989;157:241-242.
32. Dobrin PB. Surgical manipulation and the tensile strength of polypropylene sutures. *Arch Surg* 1989;124:665-668.
33. Szarmach RR, Livingston J, Edlich RE. An expanded surgical suture and needle evaluation and selection program by a healthcare resource management group purchasing organization. *J Long Term Effects Med Implants* 2003;13(3):155-170.

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This manual was illustrated by:

*Craig A. Luce, MS.
Charlottesville, VA*



150 GLOVER AVENUE
NORWALK, CT
06856

1-800-722-8772

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