CHAPTER

4

Arthroscopic Knot Tying

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Knot tying is a basic surgical skill that has been practiced for centuries. The knots used today have their roots in fishing and sailing. These basic knots have been tailored and customized into thousands of variations with both specific and general uses. The advent of endoscopic surgery placed new demands on surgeons and their ability to tie effective knots. Endoscopic and arthroscopic knots must be delivered over a distance to tissue with limited manual access. This presents new technical challenges, requiring surgeons to learn new techniques while still adhering to sound principles.

Despite the large number of knot options, all effective knots must meet two criteria: (1) the knot must be properly formed so the suture does not slip or cut into itself, and (2) it must be easily tightened to ensure maximum strength. The arthroscopic knot is simply a knot that must be formed at a distance and then tightened at the level of the target tissue. This is generally where the difficulty arises. Maintaining tension is more important than the knot configuration chosen.

The purpose of this chapter is to define the nomenclature associated with arthroscopic knots, provide a framework for successful and reproducible suture management and knot tying, review various techniques, and provide examples of currently used knots and sutures.

Definitions

When a suture has been passed through tissue (or the eyelet of a suture anchor), it creates two limbs. The *post* is the limb of suture that the other limb will be looped or passed around. This limb is generally held under tension during the tying and delivery of knots. The post defines the side of the tissue where the knot will ultimately sit. The *loop* is the limb that is passed around the post to create the knot. It is also known as the *nonpost* or *wrapping* suture. Although these limbs can be assigned arbitrarily by the surgeon, some thought should be given to where the knot stack will sit. For labral fixation in the glenohumeral joint, for instance, it is beneficial to choose the limb away from the glenoid articular surface as the post limb, so that the knot stack does not articulate with the humeral head. Similarly, during arthroscopic rotator cuff repair, the post limb should be the limb passing through the tendon so that the knot stack will approximate the tissue to the greater tuberosity.

When knots are constructed from consecutive loops tied around a post, certain concepts become important. *Post switching* or *reversing* is a technique by which the post and loop are alternated for each successive loop. Similarly, *reversing throws* refers to the direction around the post in which the loop is formed. Loops are generally referred to as underhand or overhand (overhand being on top of the post). These techniques have benefits that are discussed in detail later.

Basic Knot Types

Arthroscopic surgeons must learn to tie two basic types of knots: nonsliding and sliding knots. Nonsliding knots are constructed in single loops outside the joint and are pulled or led down sequentially into the joint. The ultimate construction and tensioning of nonsliding knots are performed *at the tissue site* in a stepwise manner. Examples of nonsliding knots are the square knot and the Revo knot.[18] The square knot is the most difficult to tie arthroscopically because, if tension is applied asymmetrically, it can convert to a sliding knot (stacked half hitches). This can result in loss of tension at the tissue site.

Sliding knots are constructed *completely outside the cannula* or joint around the post limb. They are delivered to the tissue site through tension on the post limb that allows the knot to slide into place. The Duncan loop (hangman's knot),[14] Roeder knot,[17] Tennessee slider, Weston knot,[22] and SMC knot[8] are just a few examples of sliding knots. A prerequisite for tying a sliding knot is the suture's ability to pass freely through the tissue (or eyelet of the suture anchor). If, after passage of the suture through the tissue, both limbs of the suture flow smoothly and freely back and forth, a sliding knot can be tied. If the limbs do not pass freely (because of tension or capture in the tissue or routing of the suture), a nonsliding knot must be tied. Sliding knots are a better option for securing tissue under tension. However, they may impart a higher degree of suture trauma, leading to failure during or after knot tying.

Sliding knots are further subdivided into locking and nonlocking knots. Locking knots are constructed in such a way that when they arrive at the tissue, a different tensioning sequence takes place and the knot can be "locked" as the loop strand captures the post. These knots maintain their tension and position at the tissue. Most sliding knots have some ability to lock. Examples of these knots are the taut line hitch,[12] Tennessee slider, Weston, and SMC knot. It is important to understand that the locking mechanism may result in loss of initial tension at the tissue as the knot folds back on itself.

Nonlocking knots require further throws for security after they have been delivered and tensioned at the tissue. Examples of nonlocking knots are the Duncan loop, overhand loop, and multiple half hitches. Tension must be maintained on the post limb to keep these knots in place. Additional throws can be passed around the post and advanced down into place.

A final category of sliding knots is the ratchet knot. These knots allow movement in only one direction. Examples of these knots are Nicky's knot,[5] the Lafosse knot, the giant knot,[6] and certain modifications of the taut line hitch.[12]

Loop and Knot Security

All knots rely on two principles for their effectiveness and their ability to securely hold and approximate tissue. The first concept is *loop security*, which is defined as the ability of the length of suture passed through the tissue (loop) to maintain the initial tension and length as the knot is delivered and tightened. Loop security can never be greater than when the knot is originally tensioned. It is therefore essential to maintain loop security while completing the knot (Fig. 4–1).[1] If, for example, a knot needed to be tied around a piece of tissue that measured 1 cm in circumference, a completely secure loop would have a circumference of 1 cm or, preferably, less. *Knot security* is the ability of the completed knot to resist slippage and, therefore, loosening. These two concepts are interrelated and partially dependent on each other. For example, a completely secure knot can be tied behind a loop that is 3 mm too long. Although the knot may not slip, it will not approximate the tissue effectively, because loop security was never achieved. Conversely, if an insecure knot is tied behind a completely secure loop, the knot will eventually slip under load, and tissue approximation will be lost. Biomechanical studies have assumed that 3 mm of knot slippage causes loss of soft tissue fixation.[11] So it is safe to assume that an initial loop that slips 3 mm while it is being tied will lose soft tissue apposition as well.[1]

Suture Management and Optimal Knot Tying

A distinct set of principles and techniques needs to be adhered to for successful knot tying, especially early in the learning process.[4,15] If a step is missed, problems can multiply quickly. Further, successful arthroscopic knot tying begins long before a knot is delivered to the target tissue. If the arthroscopist adheres to these fundamental principles, suture management and delivery of sound arthroscopic knots will be less intimidating.

Cannulas

It is important to note that effective and efficient cannula usage begins with portal placement. Arthroscopic knots must be tied through a cannula, which should be placed directly over, or as close as possible to, the area to be tied to avoid soft tissue interposition. Maintenance of the cannula over the proposed knot area and in line with the sutures minimizes suture chafing on the edge of the

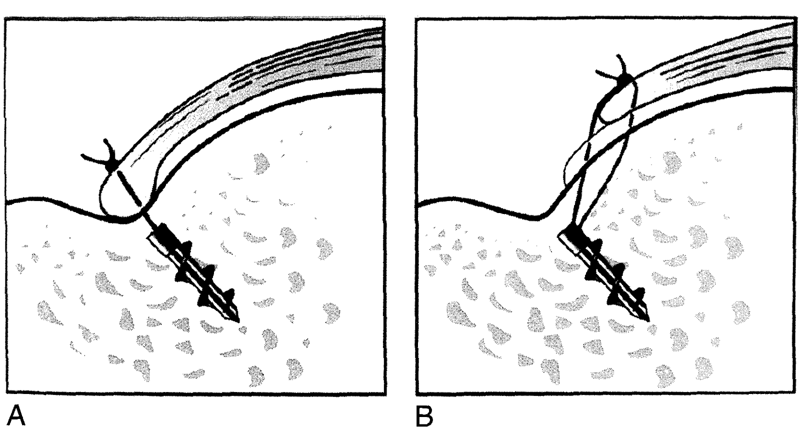

Figure 4–1 *A*, Secure initial loop holds the soft tissue tightly apposed. *B*, Lack of initial loop security leads to loss of apposition, regardless of knot security. (From Burkhart SS, Wirth MA, Simonick M, et al: Loop security as a determinant of tissue fixation security. Arthroscopy 14:773–776, 1998.)

cannula. Clear cannulas improve visualization of sutures and knots along their entire course. It is easier to avoid and correct tangles if the suture can be seen through the cannula with both the arthroscope and the naked eye outside the joint. Threaded cannulas prevent inadvertent dislodgment due to fluid pressure or instrument passage. Cannula size is determined by the largest instrument required to pass through it.

Anchor Orientation and Suture Passage

Thought should be given to the orientation of the suture limbs as they pass through the tissue alone or through the eyelet of an anchor and the tissue. If anchors are used, the eyelet of the anchor should be oriented with its open face perpendicular to the path of the suture through the tissue (i.e., parallel to the tissue to be sutured) (Fig. 4–2). If the anchor is rotated 90 degrees, the suture can be frayed as it passes acutely around the eyelet into the tissue. These problems occur primarily with anchors that have metal eyelets and less commonly with bioabsorbable or suture eyelets.

The surgeon must be familiar with whatever anchor device he or she is using to ensure that the correct limb arrangement is maintained in the cannulas during passage. Specifically, the limb exiting the eyelet of the anchor closest to the tissue to be sutured should be passed. This ensures easy and smooth sliding and avoids twists (see Fig. 4–2). If a double-loaded anchor is used, care should be taken not to overlap the sutures as they exit the eyelet. Passing and tying the distal suture first minimizes friction on the second, more proximal suture during passage.

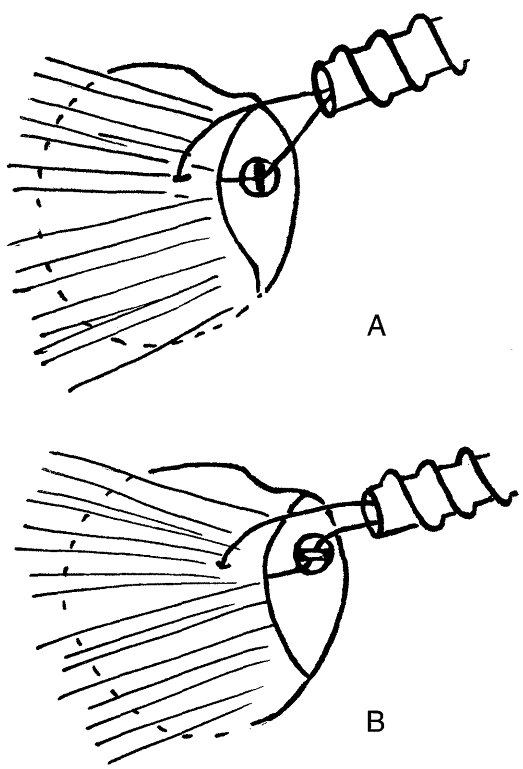

Figure 4–2 *A*, Correctly rotated suture anchor allows suture to pass perpendicularly into tissue edge without twisting. Note appropriate passage of limb closest to tissue to optimize sliding characteristics and minimize potential fraying of suture through eyelet. *B*, Anchor rotated 90 degrees produces twist as suture passes through eyelet; when tensioned, this can lead to decreased loop security and poor suture sliding.

Single Suture Sets Inside a Cannula

Only one set of suture limbs should be inside an operative cannula during knot tying and delivery. If multiple sutures are being used, a second portal can "store" the sutures, or they can be placed adjacent to the cannula in the subcutaneous tissue. This principle holds true even for double-loaded suture anchors.

Avoidance of Twists

The suture limbs must not be crossed inside the cannula. If the knot is twisted during delivery, it can lead to loss of loop or knot security and premature knot failure. First, the knot pusher should be advanced down either limb of suture into the joint under arthroscopic vision; this can avoid or correct any crossed or twisted sutures and help identify the post limb. After confirming that there are no twists in the suture limbs, the separated limbs can be placed off to respective sides of the cannula to keep them from twisting later. At this point, a clamp can be placed behind the knot pusher on the post strand to remind the surgeon which side of the cannula the post is on and to avoid confusion between the strands. To avoid suture twisting while actually tying the knots, have an assistant place a finger in the junction of the post and loop while the loops are formed to keep them separated (Fig. 4–3). Double-loaded anchors with same-color sutures should be differentiated by marking one suture with a sterile marking pen at the level of the anchor and at both tips

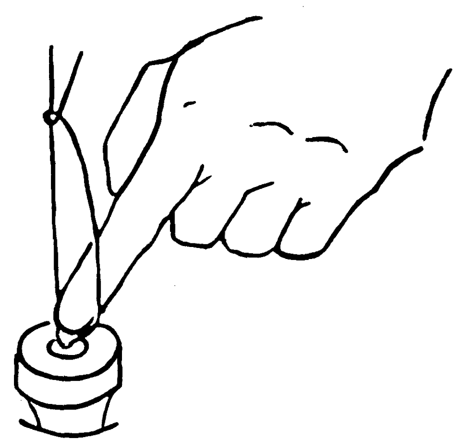

Figure 4–3 Placing a finger in the axilla formed by the suture limbs close to the cannula keeps the limbs separated and makes complex wrapping easier.

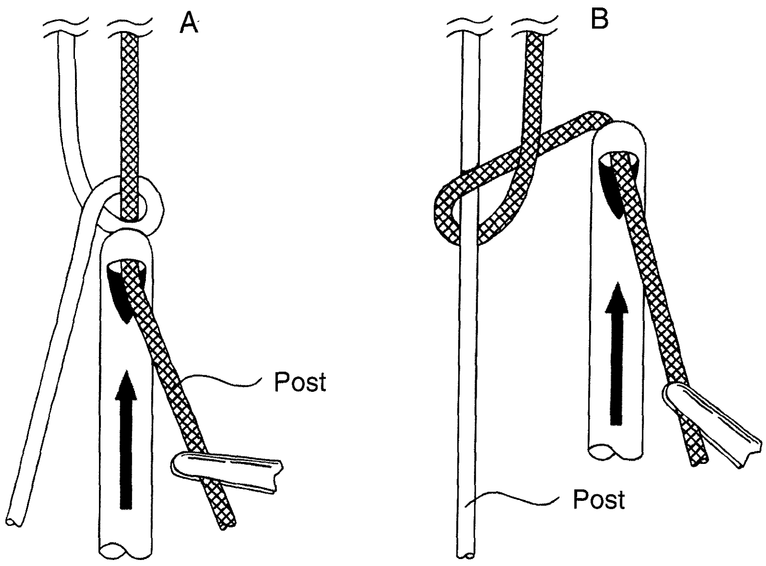

Figure 4–4 *A*, Pushing an overhand loop down the post with the knot pusher results in jerky tensioning, which can lead to tangles and passage of the knot pusher through the loop. *B*, Without switching the knot pusher, the post strand can be converted to the nonpost by pushing the knot pusher past the loop along the post. The result is an underhand loop around the original nonpost limb that can now be pulled smoothly into the joint. (From Chan KC, Burkhart SS: How to switch posts without rethreading when tying half-hitches. Arthroscopy 15:444–450, 1999.)

of the same suture to identify them as they lie outside the cannula.

Appropriate Use of Knot Pusher

Knots should be advanced to the target with a knot pusher and by appropriate tension on the limbs. For sliding knots, the knot pusher should be on the post limb and the knot *pushed* down to the target. Tension should be maintained on the post strand alone while these knots are delivered. This technique ensures initial loop security and allows the knot to be progressively tightened through simultaneous tension on the post and pressure with the knot pusher. Care is used to avoid a mismatch of tension and pressure and to deliver the knot without residual slack between the anchor and knot.

When the knot pusher is used to push half-hitch loops down a cannula (i.e., placing the knot pusher on the post limb to push the loop into the joint), several problems can arise. The knot pusher can easily slip through the loop and not advance it at all. Tension has to be applied alternately on and off both strands to advance the knot. This can lead to fraying of braided suture. These problems in combination can result in a greater chance of tangles within the cannula. Finally, with the knot pusher on the post strand, effective past-pointing cannot be achieved. When passing half hitches, therefore, the knot pusher is most effectively used to *pull* or lead the loops down to the target, much like an index finger is used during open single-handed knot tying in a deep wound. This method ensures smooth delivery of the individual knot loop down the post and allows for effective past-pointing. As the knot pusher is advanced, tension is applied to the post and nonpost in an alternating fashion. It is important to realize that by pulling a loop into the joint, the surgeon can "switch" the post limb and nonpost limb simply by pushing the knot pusher past the loop without moving the knot pusher to the nonpost limb (Fig. 4–4).[2] This achieves two goals: it allows the surgeon to pull a loop into the joint without switching the knot pusher from limb to limb, and it can provide a convenient way to tie alternating post half hitches. The technique of pulling or leading half-hitch loops down a post is used in a number of nonsliding knots (e.g., Revo knot). Effective past-pointing of the loop limb at 180 degrees to the post limb between sequential loops maximizes the tension and security of the final knot.

There are many commercially available knot pushers. Simple, single-holed knot pushers are most commonly used and are sufficient for all types of knots. Other types of knot pushers include double-holed and cannulated double-diameter knot pushers (Surgeon's Sixth Finger, Arthrex, Naples, FL) (Fig. 4–5). Double-diameter knot pushers allow the initial loop to be held in place by the inner pusher while another loop is advanced by the outer one. A comparison of hand-tied knots and knots tied with either a standard single-holed knot pusher or a cannulated double-diameter knot pusher showed that knots tied with the double-diameter pusher achieved similar loop security to hand-tied knots and significantly better

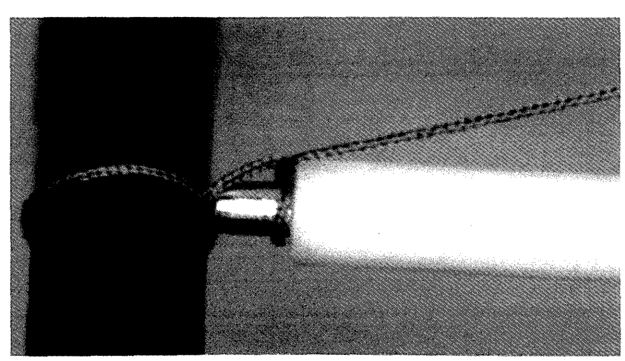

Figure 4–5 Double-diameter knot pusher holds the initial loop secure while subsequent loops are advanced down with the outer pusher. (From Burkhart SS, Wirth MA, Simonick M, et al: Loop security as a determinant of tissue fixation security. Arthroscopy 14:773-776, 1998.)

loop security than those tied with the standard knot pusher.[1] The double-diameter pusher is an excellent tool to help maintain a secure initial loop while additional half hitches are thrown, but it is somewhat difficult to use initially.

Suture Materials

A variety of suture materials has been used in arthroscopic surgery. Choice of suture material should be based on the inherent suture characteristics and the surgeon's familiarity with the material. Suture material is classified by its absorbability and whether it is monofilament or braided.

The absorbable sutures used in arthroscopic knot tying can be braided (Panacryl, Ethicon, Somerville, NJ) or monofilament (PDS [polydioxanone suture]). Absorbable sutures, by design, lose strength as they are degraded but usually start out at a lower tensile strength than nonabsorbable sutures of the same caliber. The most commonly used nonabsorbable suture material in arthroscopy is braided polyester. Recently, braided polyester suture reinforced with Kevlar (Fiberwire, Arthrex, Naples, FL) has become popular. The principal limitation of nonabsorbable suture is its permanency inside the joint and its possible mechanical or abrasive effects.

Tying characteristics are dependent more on the suture construction than on the material properties. Braided suture is more pliable, less ductile, stiffer,[10] and generally easier to tighten. It tends to fray with handling, however, and its rough surface may decrease its ability to slide but improve internal frictional ability and decrease the likelihood of loop loosening. Monofilament suture is smooth and therefore tends to slide better. It is stiffer to work with, however, and knot security is difficult to maintain. Monofilament suture (PDS in particular) has memory and recoil, making it more ductile. In one biomechanical study, the most important factor affecting knot security was suture material.[14] A high percentage of knots tied with monofilament suture failed due to knot slippage, even when tied with alternating post and throw half hitches. In contrast, knots tied with braided material failed more often by suture breakage. In a specific comparison of the same stacked half-hitch knots tied with either number 2 PDS II or number 1 Ethibond (Ethicon, Somerville, NJ), the Ethibond knots had a 50% higher knot-holding capacity.[3]

Specific Knot-Tying Techniques

At a minimum, the arthroscopist must be able to tie a nonsliding knot, because there are times when the limbs will not slide. Because loop security can be improved with sliding knots (which may or may not lock), the surgeon should also learn to tie a sliding knot. The specific knot used is immaterial; it is only important to be able to achieve loop and knot security in a reproducible fashion. Therefore, it is recommended that the arthroscopist practice knot-tying techniques outside the operating room to master this skill (see also reference 13).

Nonsliding Knots

Nonsliding knots can be used any time during arthroscopy; there are no absolute prerequisites for their use. Nonsliding knots may not be the ideal choice when tissue is under tension, however. They are also more difficult to secure when using monofilament suture, owing to the low coefficient of friction and its stiffness. All nonsliding knots are combinations of half-hitch loops. Therefore, the surgeon must learn how to throw and secure half-hitch loops effectively. The knots described here are stacked half hitches and the Revo knot.

Stacked Half Hitches

Half hitches are the surgeon's workhorse. They are familiar to most surgeons owing to their routine use in open surgery. Stacked half hitches can be tied with alternating posts or throws or any combination of the two. Biomechanical studies have evaluated the importance of reversing posts or throws for knot security.[3,11,12] The most secure half-hitch knots are those in which the post and direction of throw are alternated. When using half hitches to back up sliding knots, the surgeon should reverse either the throws or the post to maximize knot security.[11] As described earlier, single loops can be pushed into the joint (down the post) or pulled (led) into place with the knot pusher on the nonpost limb. Pulling the loops into place results in smoother passage and minimizes suture fraying and tangles.[15] Remember also that the post limb can be switched by alternate tensioning while the knot is being advanced.

To tie stacked half hitches:

1. Maintain the limbs of the suture at equal lengths. Determine which limb is the post by sliding the knot pusher down into the joint and removing all twists. Tag the post with a clamp to identify the suture limbs and separate them.
2. Throw an overhand loop around the post, and pull the knot down to the target with the knot pusher on the nonpost. As the knot pusher is advanced, keep continuous tension on the post, and alternately apply tension and release it on the nonpost. Past-point the post and loop limbs at 180 degrees to each other with the knot pusher.
3. Switch the knot pusher to the other strand (the original post) and throw an underhand loop around the new post. Pull this loop into the joint and apply tension by past-pointing while maintaining tension on the post strand.
4. Continue in this fashion with reversing posts and alternating throws for a total of five loops.

This method of tying half hitches is the most effective at maintaining knot security.[3,11] However, different strategies are frequently and effectively employed. To help improve loop security, a surgeon's knot can be tied initially. Two identical loops around the same post create the surgeon's knot and allow the tissue loop to be further tensioned after the first throw. Internal friction between the two same-direction throws is usually sufficient to maintain the loops in place. Subsequent loops can then be thrown with reversing posts and throws to increase knot security.

Revo Knot

As stated earlier, all nonsliding knots are a combination of various half-hitch loops. The Revo knot (Fig. 4–6) is no exception.[18] To tie a Revo knot:

1. Throw an overhand loop around the post with the knot pusher on the post and advance it down into the joint.
2. Maintain continuous tension on the post, throw a second identical half hitch (i.e., overhand) around the same post, and advance it down on top of the initial loop (effectively throwing a surgeon's knot).
3. Tension both loops by applying continuous tension on the post and pushing on the knot stack while tensioning the nonpost.
4. Wrap a third half-hitch loop in the opposite direction (i.e., underhand) around the post limb, advance it to the knot stack, and tension as above.
5. Switch posts, throw an overhand loop, advance to the knot stack, and tension it as above with past-pointing. This throw effectively locks the initial three loops thrown around the original post. Therefore, it is paramount that all slack in the knot stack be removed before this throw.
6. To complete the knot, reverse the post again, tie an underhand loop around the new post, and tension as above.

Sliding Knots

The basic requirement for tying a sliding knot (locking or nonlocking) is that the suture must slide through the tissue and anchor freely. If the suture does not slide, the surgeon must use a nonsliding knot. Sliding knots have a number of advantages over serial half-hitch throws. These knots can be constructed completely outside the cannula and joint and then slid down into place. They have better loop security and require fewer steps to tie once the wrapping sequence is learned. Problems with sliding knots are usually encountered when the suture does not slide as planned. Locking sliding knots can lock prematurely and bind in the cannula; this problem may not be recoverable.

Sliding knots are generally more complicated to tie than are half hitches and other nonsliding knots. Successful use of sliding knots depends on smooth sliding of the knot, easy passage through the cannula, and maintenance of loop tension while the knot is secured in place. There is a significant learning curve associated with these knots. In addition, their sliding and holding characteristics vary from surgeon to surgeon, underscoring their technique-dependent nature.[7]

Nonlocking Sliding Knots

Nonlocking sliding knots cannot prematurely lock and bind the post before they are tensioned at the tissue. These knots require backup half hitches to secure the knot once it is in place. If no backup loops are thrown, these knots will lose loop security by sliding back up the post limb. Here we describe the Duncan loop (hangman's knot) and the Roeder knot.

Duncan Loop

To tie the Duncan loop (Fig. 4–7)[14]:

1. As always, identify the post and ensure that there are no twists or tangles along the sutures in the cannula. Slide the suture so that the nonpost is about twice as long as the post strand. Place a knot pusher and clamp on the post limb, and hold both limbs between the thumb and long finger.
2. Wrap the loop strand over the thumb, creating a loop, and then wrap it over and around both limbs four times.
3. Pass the free end of the loop strand back through the loop formed around the thumb.
4. Remove excess slack (i.e., dress or set) in the knot by pulling on the free end of the loop strand and then tensioning the loop strand from the knot to the cannula. This is facilitated by placing an index finger just distal to the loop stack in the axilla at the junction of the post and loop limb.
5. The knot can now be slid into place by simply pulling on the post limb. As it is advanced, push it into

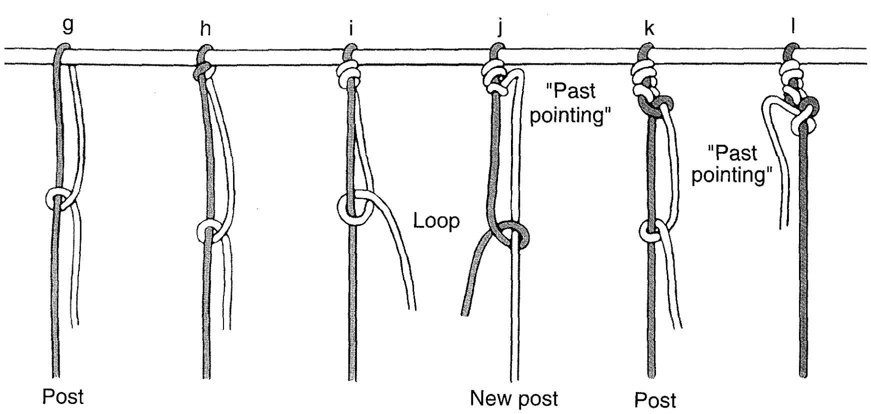

Figure 4–6 Revo knot. (From Nottage WM, Lieurance RK: Arthroscopic knot tying techniques. Arthroscopy 15:515-521, 1999.)

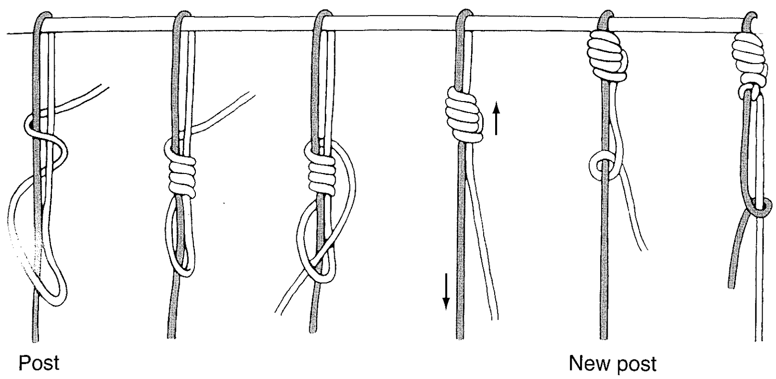

Figure 4–7 **Duncan loop.** (From Nottage WM, Lieurance RK: Arthroscopic knot tying techniques. Arthroscopy 15:515-521, 1999.)

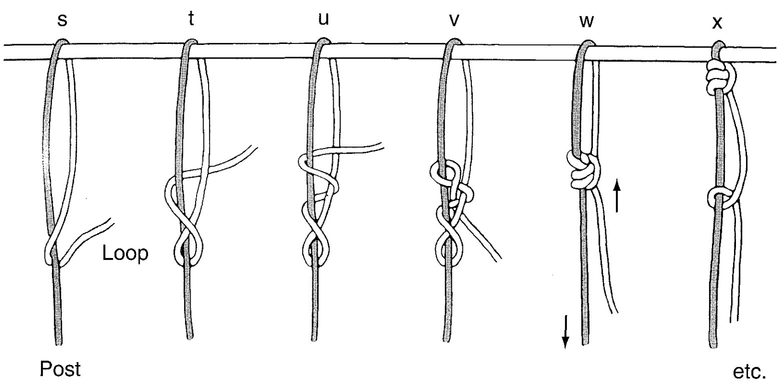

Figure 4–8 **Roeder knot.** (From Nottage WM, Lieurance RK: Arthroscopic knot tying techniques. Arthroscopy 15:515-521, 1999.)

place with the knot pusher to minimize suture trauma.

6. Continue pushing on the knot as the post is tensioned. While keeping continuous tension on the post, throw a half hitch around the post and advance it into place behind the Duncan loop.
7. Continue throwing a minimum of three reversing half hitches on alternate posts to secure the knot.

Roeder Knot

The Roeder knot (Fig. 4–8) is a modification of the Duncan loop.[17] It consists of the same number of loops and has the same characteristics as the Duncan loop. To tie the Roeder knot:

1. As always, identify the post and ensure that there are no twists or tangles along the sutures in the cannula. Slide the suture so that the nonpost is about twice as long as the post strand. Place a knot pusher and clamp on the post limb, and hold both limbs between the thumb and long finger.
2. Throw a loop over and around the post strand.
3. Throw a second loop over both strands.
4. Throw the third loop over only the post strand.
5. Pass the free end of the loop strand down between the second and third loops from above the knot.
6. Dress the knot and slide it into place by pulling on the post strand and pushing the knot down with the knot pusher. Secure the knot with a series of three alternating post and throw half hitches.

Locking Sliding Knots

The advantages of locking sliding knots are that they can be constructed completely outside the joint and, once delivered to the tissue, provide loop and knot security without further steps. Most surgeons throw additional locking loops behind these knots to ensure knot security, however. Potential problems are related to the knots' complexity. They rely on multiple loops around one or both limbs and proper sequencing of the loops. Additionally, these knots can lock prematurely if tension is applied on the nonpost limb before the knot is seated. Unfortunately, this problem usually cannot be fixed and may require starting with a new anchor. Despite the potential shortcomings, these knots are excellent choices for tissues under tension. They can be used effectively any time the suture slides freely through the anchor.

Tennessee Slider

The Tennessee slider (Fig. 4–9) has all the advantages of locking sliding knots,[15] plus the added advantages of being low profile and low volume. Unfortunately, it is difficult to tie and can bind prematurely. To tie the Tennessee slider:

1. As always, identify the post and any twists with a knot pusher and mark the post with a clamp.
2. Slide the suture until the nonpost limb is twice as long as the post, and grasp both limbs of the suture between the thumb and index finger.

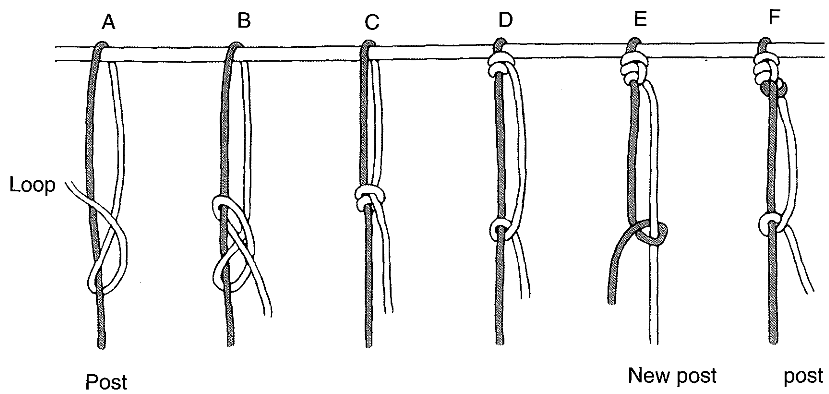

Figure 4–9 Tennessee slider. (From Nottage WM, Lieurance RK: Arthroscopic knot tying techniques. Arthroscopy 15:515-521, 1999.)

3. Pass the wrapping strand over the post, and continue wrapping outside and proximal (closer to the surgeon) to the loop just created.
4. Pass the wrapping strand back over the post.
5. Reach between the wrapping strand and the post and pull the free end of the suture up through the loop created by the second overthrow.
6. Dress the knot and remove slack, but *do not tension the loop strand.*
7. Place the knot pusher on the post strand and advance the knot into the joint by pulling on the post and pushing with the knot pusher.
8. Maintain tension on the post, and tension the wrapping strand to capture the post and lock it into place. It is critical to maintain tension on the post, because this knot has a tendency to lose some of its initial tension as it is locked.
9. Throw a minimum of three additional half hitches on alternating posts to ensure security.

SMC Knot

The SMC knot (Fig. 4–10) was recently described as a new type of locking sliding knot.[8] It provides excellent initial loop and knot security and has a low profile. It can be backed up with half hitches to improve on its already excellent inherent security. It also relies on an internal locking mechanism to capture the post once it is deliv-

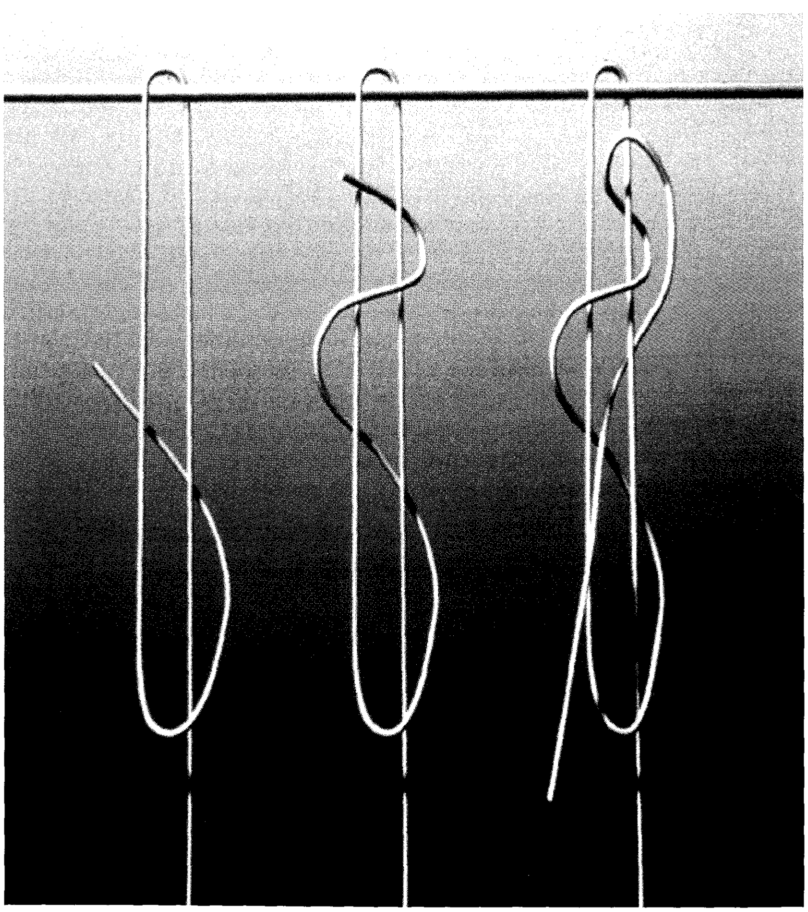

Figure 4–10 SMC knot. (From Kim SH, Ha KI, Kim JS: Significance of the internal locking mechanism for loop security enhancement in the arthroscopic knot. Arthroscopy 17:850-855, 2001.)

ered to the tissue. Unlike the Tennessee slider, it does not tend to "back off" the tissue as it is being locked and therefore maintains its loop security. In biomechanical studies, this knot fails through suture breakage rather than knot slippage.[9]

To tie the SMC knot:

1. As always, identify the post and any twists with a knot pusher and mark the post with a clamp.
2. Slide the suture until the nonpost limb is twice as long as the post, and grasp both limbs of the suture between the thumb and index finger. Have an assistant place a finger between the strands to keep them separated as the knot is tied.
3. Begin the knot by passing the loop strand over the post strand and then over both strands again (see Fig. 4–10*A* and *B*).
4. Reach between the post and loop strands, grab the free end of the loop strand, and pass it over only the post strand (see Fig. 4–10*B*).
5. Pass the free end of the suture under the post between the first two throws, and leave a loop of suture. Lightly dress the knot, but *do not pull on the loop strand* (see Fig. 4–10*C*).
6. Advance the knot to the tissue by pulling on the post and pushing the knot into place with the knot pusher. The knot can then be locked by pulling on the loop strand to incorporate the locking loop into the knot and capturing the post. The loop strand now becomes the new post.
7. Additional half hitches can be thrown to further secure the knot.

Knot-Tying Alternatives

Many devices have been developed to avoid knot tying in arthroscopic surgery. Staples and tacks have been used with mixed results in the fixation of labral and rotator cuff repairs. Recently, knotless suture anchors have been developed that combine the benefits of suture through tissue and a bone anchor.[19–21] These knotless anchors compare favorably with standard suture anchors in pull-through strength because when they are implanted, there are effectively two strands of suture through the tissue (Fig. 4–11).[20] Although this is an attractive option, there are limitations. Only a fixed and maximal amount of tissue volume can be captured, leading to a theoretically limited ability to address capsular redundancy. The somewhat larger insertion cannulas required may also limit inferior placement in some conditions. These anchors, however, can provide secure fixation and avoid the need for arthroscopic knot tying.

Ultrasonic suture welding seeks to retain the benefits of suture passage through tissue without the need to tie knots. This technique employs an ultrasonic wand that imparts heat to a loop of polypropylene (monofilament, nonabsorbable) suture to "weld" it together (Fig. 4–12). It can be passed down a cannula and used arthroscopically. Biomechanical studies have shown that a number 2 suture welded together has better strength, less elongation at failure, and a higher load to failure under cyclic loading conditions than the same suture tied with traditional knots.[16] This technique is operator dependent, however, and involves additional equipment and

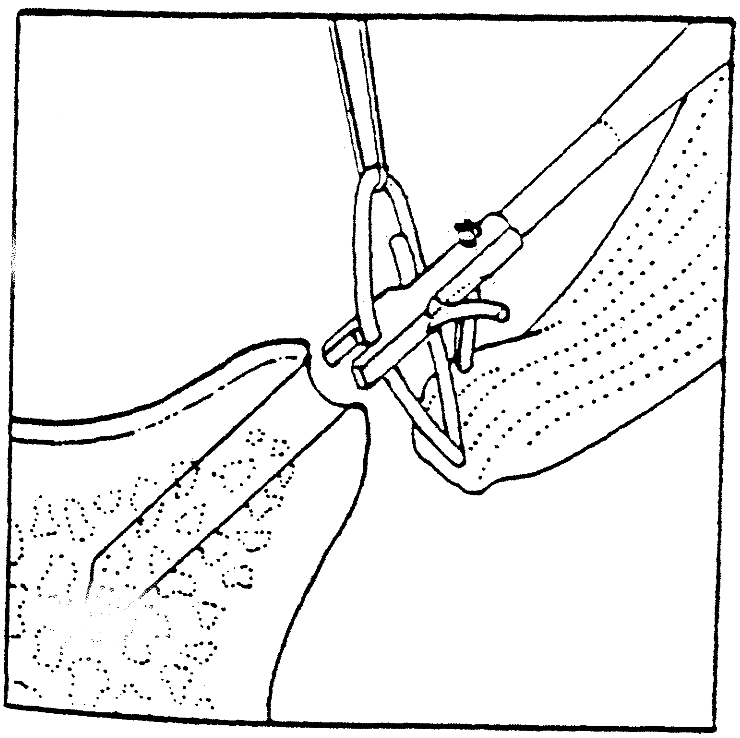

Figure 4–11 **Knotless suture anchor. The anchor has a utility suture fed through the loop attached to the anchor. A shuttle is passed through the tissue, and the loop is pulled through via the utility suture. The pronged end of the anchor is then used to grab the loop and advanced into the tunnel.** (From Thal R: A knotless suture anchor: Technique for use in arthroscopic Bankart repair. Arthroscopy 17:213-218, 2001. With permission from The Arthroscopy Association of North America.)

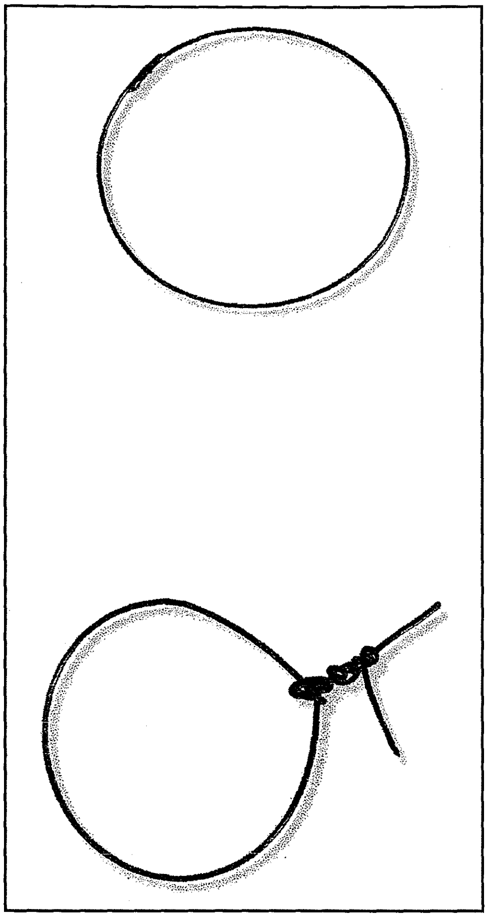

Figure 4–12 **Welded suture (top) compared with a traditionally tied suture.** (From Richmond JC: A comparison of ultrasonic suture welding and traditional knot tying. Am J Sports Med 29:297-299, 2001.)

cost. It also cannot be used with braided nonabsorbable sutures.

Conclusion

We have presented a framework for successful arthroscopic knot tying. This chapter is intended to be a guide for surgeons to organize their thoughts and plan accordingly for surgery. Proficiency with these techniques, like any other surgical skill, requires practice and meticulous attention to detail. The steps involved in effectively and efficiently tying arthroscopic knots start with portal placement and do not end until the suture is cut.

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