Creating Secure Ligations
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Introduction- Importance of Ligations

Ligation involves the use of encircling suture material and a knot, called a ligature, to tightly occlude blood vessels in surgery. Despite the introduction of newer electrosealing devices for use in open and minimally invasive surgery now available to veterinarians for large vessel hemostasis, ligatures are still considered the gold standard method to achieve hemostasis. Ligation of solitary vessels, or multiple vessels within a pedicle (mass ligation) is used virtually every day in practice during ovariohysterectomy, castration, amputation, splenectomy, and lobectomies; therefore, creating secure ligations is one of the most critical life-saving steps in most soft tissue surgeries.

Suggested Suture Material Choice and Size for Ligation

Although a number of sutures can be used successfully to ligate a pedicle or critical blood vessel, most surgeons choose strong absorbable monofilament material (such as polydioxanone -PDS, polyglyconate –Maxon, glycomer 631 –Biosyn, polyglecaprone 25 –Monocryl) of 0 to 3-0 size for most small animal applications. For larger arteries, some surgeons still recommend monofilament nonabsorbable suture material, such as polypropylene. Multifilament sutures such as silk, a suture noted for its excellent handling and ligation qualities, can be used successfully for ligation but these sutures have been shown to increase the risk of suture-related wound infections. In addition, generally speaking, multifilament suture materials tend to lockup prematurely during tying (the first throw of the knot may not tighten fully around the vessel or pedicle) since the suture develops more friction between strands compared to the monofilaments. Chromic catgut suture has fallen out of favor for ligation because the suture is much weaker than the aforementioned materials, even after careful knotting. Catgut suture within standard square knots often shows signs of fraying, which weakens the ligation. Hence, if friction knots, mentioned later, are used on a ligature, chromic catgut is contraindicated due to the risk of excessive abrasion and fraying of the multifilament strands during tightening. Knot ears should be cut at least 3 mm for synthetic sutures. Within the recommended suture size range listed, larger size suture materials are generally chosen for more substantial vessels or bulky pedicles. Generally speaking, it is good practice to choose the smallest suture material size providing sufficient strength for the intended ligation.

Testing the Security of Ligations

One of the most common but dangerous ways surgeon's attempt to "test" their ligations to be sure they are leak-proof is to carefully and slowly release the clamps and any tension on the ligated pedicle, and watch to see if bleeding occurs from the cut end. Realize that simply crushing the vessel or pedicle with a hemostatic forceps

can *temporarily* stop bleeding particularly when the patient is hypothermic and somewhat hypotensive. In addition, any tension on the pedicle can also *temporarily* occlude flow through the vessel and this can give the surgeon the false impression that "all is well" at that site. Most seasoned surgeons, the author included, have experienced a latent bleed after a splenectomy or lobectomy, even though there was absolutely no evidence of bleeding from any pedicle at the time of approach closure. As the patient is warmed and the hypotensive effects of the anesthetic drugs wear off, blood pressure rises, and any fragile clot at the ligated site or crushed area can dislodge with the extra pressure and blood flow. Unfortunately, especially when the ligature knot crushes deep within the pedicle during tightening, it is quite difficult to know for sure that safe and permanent hemostasis has been achieved. It may appear to be tight but it only takes a millimeter or two of loosening at the ligature knot to create a potentially life-threatening situation. Meticulous surgeons safely practice the principles of secure ligation (Table 1), rather than solely relying on whether the pedicle is found to bleed or not soon after the ligation is completed.

Table 1
Rules for Consistently Secure Ligations

- Double ligate critical blood vessels or pedicles
- Transfix large vessels and pedicles especially when there is no "mushroomed" wad of tissue distal to the ligation(s). This expanded end helps hold the ligation in place since the thinner crushed area acts like a "waist" reducing the risk of slippage. With this in mind, short, stout vessels in close proximity to the aorta are always transfixed since no cuff of tissue is available distal to the ligation.
- Use a 3-forceps technique if you choose to clamp the pedicles before ligation. Classically, hemostatic forceps are clamped one-by-one proximally (deeply) to distally (more superficial) (numbered 1-3 respectively) along the pedicle or vessel. The pedicle is cut between clamps 2 and 3, leaving clamps 1 and 2 on the pedicle to be ligated and #3 left with the "part" to be removed. The first circumferential ligature is placed just proximal to clamp 1, and the second ligature (circumferential or transfixing) is placed proximal to clamp 2. The transfixing ligature is *always* placed distal to the first ligature since this ligature requires needle penetration of the vessel, and the first circumferential ligature safely occludes the vessel first.
- Do not attempt to place a ligation on a vessel or pedicle close to a hemostatic clamp unless the clamp is "*flashed*" or loosened and the throw can be retightened. Adjacent to the clamped area of a pedicle, the tissue is deformed and "fanned out", which tends to loosen the first throw inadvertently. Use a Miller's or Strangle knot (described in the text) especially when you are performing surgery solo, and release of the clamp during ligation is deemed to be too risky. If the clamp must be left in place, position your ligature as far away as possible from the deformed tissue within the clamp.

- Ideally, if the clamp can be flashed, attempt to move the ligature so it falls in the crushed area of pedicle after the hemostat has been "flashed".
- Tension on the pedicle during knot tying also tends to loosen the first throw of a ligation. This tension also tends to fan or spread out the pedicle which increases the risk of loosening of the first throw. If the first throw loosens just a small amount, this could result in fatal hemorrhage. Use a Miller's or Strangle knot when tension on the pedicle cannot be avoided. This happens commonly when attempting ligation of a relatively short ovarian pedicle during ovariohysterectomy in a deep-chested dog.
- Choose strong suture material with good knot security. Place firm, slow and even tension on the knot throws during tightening so the throws are squarely fashioned. Avoid sawing suture strands as the ligature throws are "pushed down" toward the pedicle. This significantly weakens the strands and knot. Knot ears should be at least 3 mm for synthetic sutures to help keep the final throw of the knot from unraveling.

Binding or Friction Knots

Binding knots are knots on a strand that either constrict a single object or hold multiple objects snugly together. Whippings, seizings and lashings serve a similar purpose to binding knots, but contain too many wraps to be properly called a knot. In binding knots, the ends of rope are either joined together or tucked under the turns of the knot. These so-called friction knots are held in place by the friction between the windings of line, or they are held in place by the two ends of the line being knotted together. Originally, these knots were designed to be performed by solo field workers to firmly close the end of burlap sacks. Binding knots were chosen because they would temporarily hold the neck of the sack tight without assistance until the knot was permanently secure with additional square throws. Some of the more common friction knots used at that time were the Miller's knot, the Constrictor knot, Strangle knot, the Double Reverse Half Hitch, and the Surgeon's knot.

During surgery, once a friction knot/throw is applied and tightened firmly it should be considered only *temporarily* stable, additional square throws are applied on top of it to make it permanently secure. In most cases, 3-4 snug, additional square throws will secure the ligature knot.

Qualities of an Ideal Friction Knot

Ideal qualities of the first throw friction knot include the ability to 1) *cinch down tightly and completely without prematurely locking up*. This characteristic allows the surgeon to "feel" when the knot does not cinch down any further during tensioning and thereby signaling when it is tightly applied, and 2) the friction knot should *resist loosening once placed* allowing time for additional throws to be performed for a permanent secure knot.

A surgeon's knot is a type of friction knot created by a double twist on the first throw (called the surgeon's throw) and it is completed with a second square, single-twist throw on top. Although the surgeon's throw can be used successfully for ligation in practice, it is generally not recommended for this use. This risky friction knot can "lock-up" prematurely, creating a dangerous situation in which the surgeon falsely thinks the knot has been tightly applied but it is not. When the strands are tensioned on a surgeon's throw, as the encircled tissue is tapered, the double twisted throw tends to bind up and resists further tightening. In addition, of the friction knots mentioned in this proceedings, it has been shown to be the *least* able to resist loosening when placed under expansile force when tested in my recent knot security research project.

Recommended One or Two-Pass Friction Knots

Friction knots commonly employed in veterinary surgery can be classified by how many passes are placed around the pedicle. One-pass friction knots are the Surgeon's knot (not recommended for ligation) and the **Double Reverse Half Hitch** knot. The highly dependable 2-pass friction knots commonly chosen in practice include the traditional **Miller's knot** and the newly introduced **Strangle knot**.

Some surgeons choose a one-pass friction knot since it is easier to apply as it requires only one pass of the suture around the pedicle or vessel. The two pass friction knots, take a bit more effort to pass twice around the pedicle but they are highly effective as first throw knots to resist loosening. *(TIP) For the two pass knots, complete a loose knot on the jaws of a hemostatic forceps first, and then push the loose knot down over the jaws into the appropriate position on the clamped pedicle after which fully tighten the knot. This enables construction of the knot in a site with ample room, before it is pushed down to crush the pedicle.*

Double Reverse Half Hitch

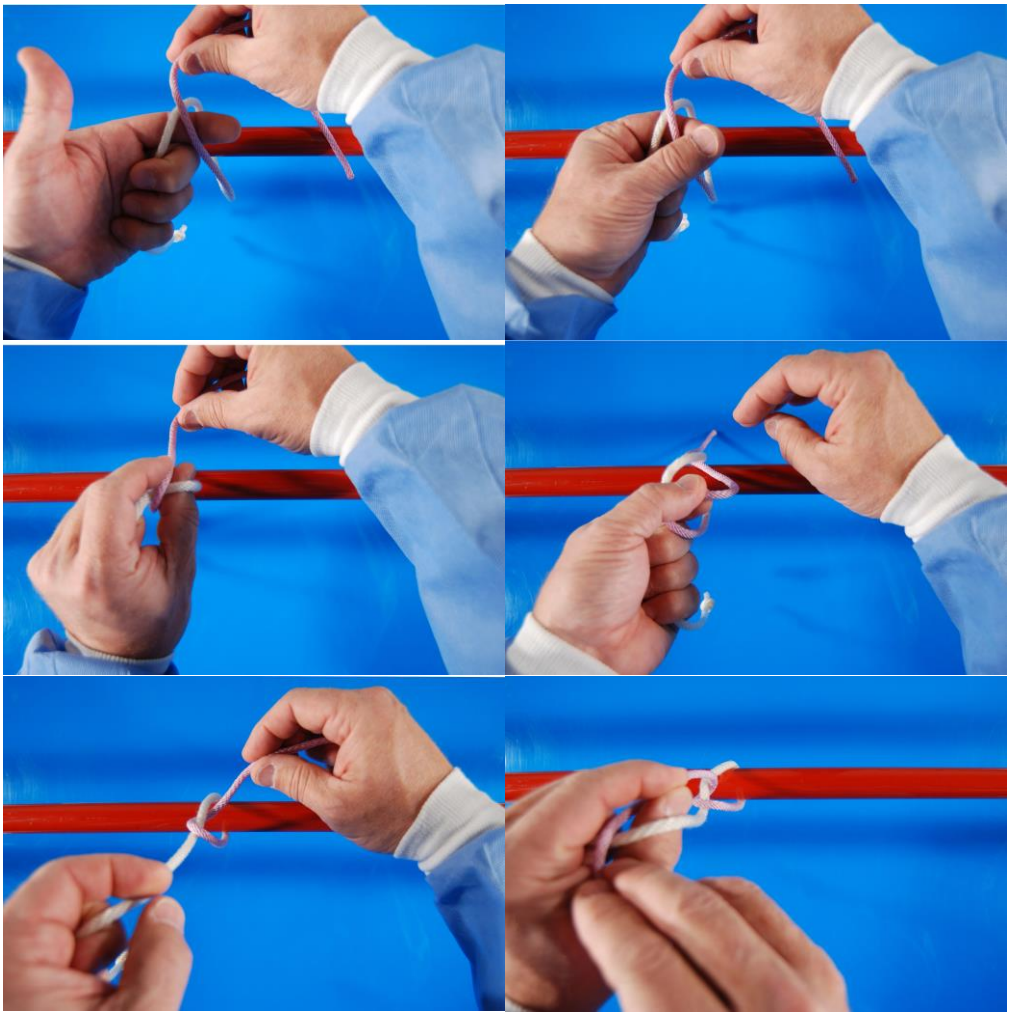
Double Reverse Half Hitch (DRHH)

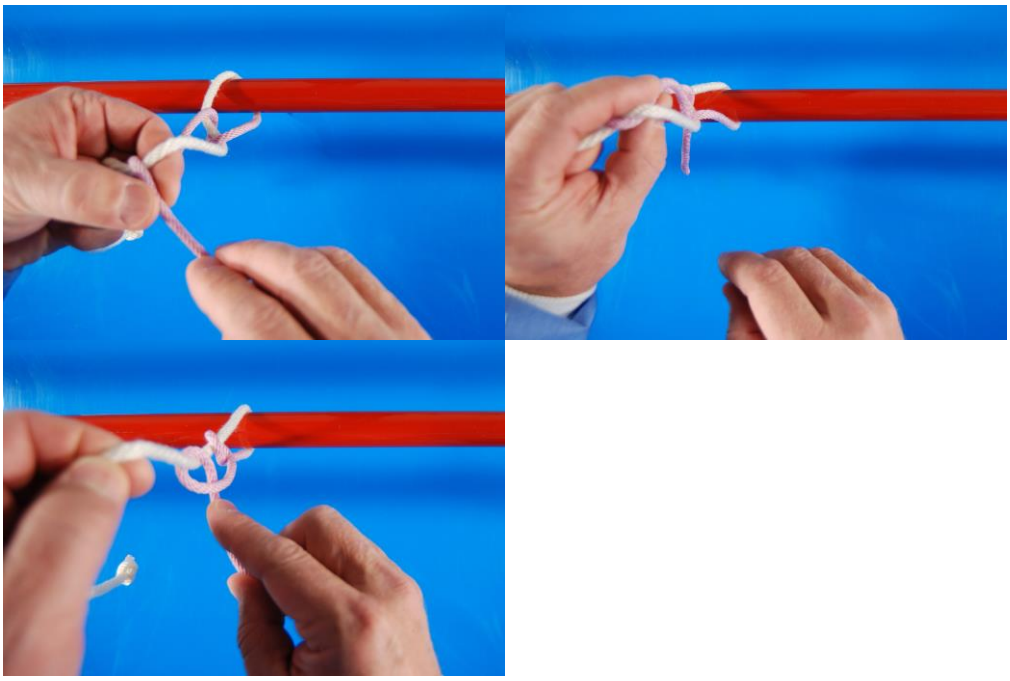
This knot can be chosen in surgeries for ligation, and to incrementally tighten and draw together two structures under moderate to high tension, such as during tying stifle imbrication sutures, or when pulling the arytenoid cartilage towards the cricoid with a suture to open the glottis in dogs with laryngeal paralysis. The author also prefers the DRHH when tying a knot deep within a body cavity, since the knot only needs one pass around or through a structure (unlike the Miller's or Strangle knot that requires two wraps). In addition, the knot can be formed outside the cavity first (where it is easy to manipulate the strands) and the loosely formed knot is slipped down to the deep structure or pedicle before it is tightened and set. This is also the knot of choice for many surgeons during attempts to bring together rigid adjacent ribs at closure of a lateral thoracotomy approach. When the ribs resist apposition due to tension during intercostal closure, this knot holds the ribs tightly together until the knot is eventually secured with additional square throws. One must realize that *this knot also may prematurely lock-up before being fully tightened,*

so close attention to knot formation and strand tension is paramount for successful use of this knot technique.

DRHH Hand Tie Technique – One-Pass Friction Knot

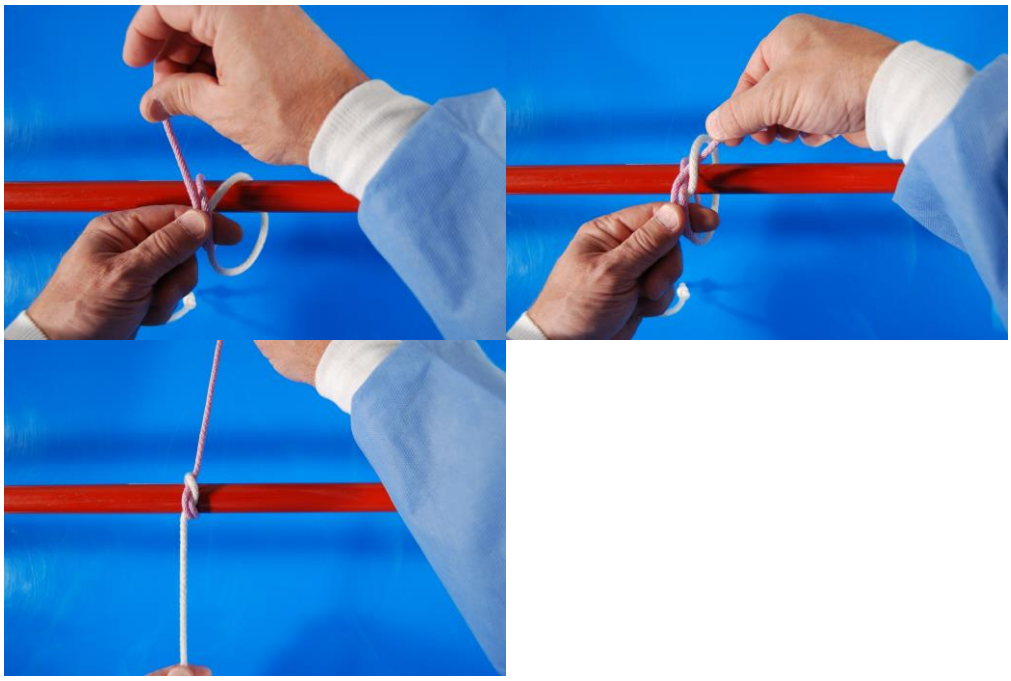
The DRHH knot is formed exactly like a standard square knot except the surgeon *purposefully* pulls up on the fixed strand while creating the two throws with manipulation of the free strand, and this converts it from a square knot to a DRHH. The double throws are slid down the more tensely held fixed strand before the knot is fully tightened. It is important that the free end is not tensioned until the hitches are pushed down to the desired intrinsic suture tension (the tension developed on the tissue encircled within the suture loop).





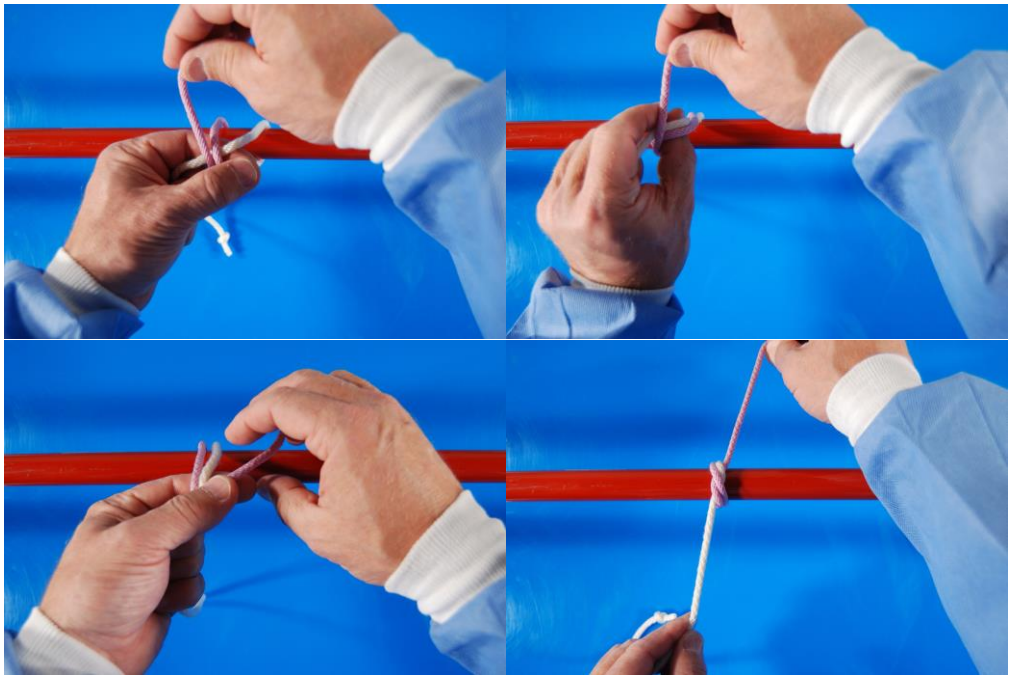
Miller's Knot (2-Pass Friction knot

A Miller's knot is the most traditionally taught friction or so-called "binding knot" used to tie-off vessels or pedicles. This knot works well on large pedicles, such as ovarian pedicles or uterine body during ovariohysterectomy, since the strands of the knot have many surfaces in contact to increase friction, and a greater surface area of compression by the multiple suture passes encircling the pedicle. This knot does not "bind up" prematurely, and allows the operator to confidently know when the knot has been tensioned correctly to obstruct blood flow through the pedicle.



Strangle Knot Hand Tie Technique

The Strangle knot is another variation of a 2-pass binding knot and can be used in lieu of a Miller's knot. The author prefers this binding knot since it tends to stay tight even when the ends are manipulated like the Miller's knot, but it is easier to tie. The only difference between this knot and the modified Millers is that the strands are crossed on the first pass, and the second pass is to the left of the first formed loop.



Summary
Ideally, a tightly placed friction knot will remain tight around a pedicle until subsequent square throws are completed, and this permanently locks the tight ligature knot in place, safely maintaining hemostasis. Not all friction knots are useful as first "throw" knots for ligation of large vessels and pedicles. Surgeon's throws are not recommended as friction knots for ligation because they can lock up prematurely, and are less resistant to loosening. Double reverse half hitch knots may lock up prematurely if the surgeon does not carefully construct the knot, but this knot is excellent at resisting premature unloosening especially under considerable tension. The traditional Miller's knot and the Strangle knot are highly recommended friction knots for ligation since they tighten fully and will not lock up, and they resist loosening with strand manipulation or expansile forces.