An Innovative Technique of Laparoscopic Knot Tying

A Qualitative Explanatory Research

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Abstract

Objective: To introduce an innovative laparoscopic knot tying technique, designed to be ergonomically more suitable, easier to learn and safer for patient and surgeon, than traditional knot tying techniques for minimally invasive surgery.

Design: A qualitative, explanatory research design is used to describe a new technique of laparoscopic knot tying.

Method: Various knot tying techniques (laparoscopic knots, surgical knots, knitting knots, fishing knots, and sailor's knots) were reviewed online using internet search engines, books and practical observation. Also, the instruments which were used to assist in knot formation were studied for closest resemblance to laparoscopic instruments' ergonomics. Methods of achieving knots with correct configuration, appropriate Shaping and Maximum Security and stability were studied. The knitting needles and hooks used for knot tying were found to resemble laparoscopic instruments. The innovative laparoscopic knot tying technique was inspired by knitting knot techniques.

Technique: Intracorporeal knot tying: Working end of suture is casted in form of capsized configuration of the slip knot, on the shaft of needle holder before it is introduced into the body for intracorporeal suturing. Slip knot is formed by pulling the needle end of suture through the casted working end.

Extracorporeal Knot tying: Working end of suture is casted in form of capsized configuration of the slip knot, on the shaft of an appropriate sized hook/appliance and the standing end is pulled through the casted working end of suture by the hook/appliance to form a slip knot extracorporeally, the knot is slid on standing end by knot pusher to the site where knot is to be applied.

This method is named as Radfar's laparoscopic knot tying technique for future references.

Conclusion: Radfar's laparoscopic knot tying technique is introduced taking into consideration:

The ergonomics of laparoscopic operative surgery

Accurate Knot reproducibility

Knot security and stability

Decrease trauma to patient tissues while applying knot

Least amount of suture material used in knot, to decrease foreign body reaction in patient's tissues

Introduction

Laparoscopic operation is different from open surgery operation in many ways. Laparoscopic knot tying is the most challenging skill a surgeon must master in transforming from laparotomy to laparoscopic surgery. Many advances and technologies like clips, staples, pre-tied suture loop ,tissue adhesives, laser tissue welding, Harmonic, Ligasure, electro-cautery are used in laparoscopic operations to ease the tasks by decreasing the need for knot tying, yet no surgeon can feel confident in attempting laparoscopic surgery before mastering the laparoscopic knot tying and suturing techniques, because as the patient safety is at stake during operation, surgeon cannot exclusively depend on these technologies which have their own limitations in applied surgery and are more expensive and machine dependent.

Ergonomics (Greek word ergon meaning work, and nomoi meaning natural laws), is the science of refining the design of products to optimize them for human use (1). Ergonomics is "the scientific study of people at work, in terms of equipment design, workplace layout, the working environment, safety, productivity, and training". Ergonomics is based on anatomy, physiology, psychology, and engineering, combined in a systems approach (2). It is ergonomically difficult for surgeon to laparoscopically tie knots.

Laparoscopic ergonomic challenges during suturing and knot tying: -

1- Decoupling of visual axis and motor axis.

The surgeons are trained to look directly to the site of operation while operating, but in laparoscopy the surgeon must look at a monitor, which is away from operation site. This causes decoupling of visual and motor axes during laparoscopic surgery.

2 - The field of vision is more limited in laparoscopy compared to laparotomy. The view of operation field is controlled by the assistant handling the scope.

3-In open surgery the surgeon has three dimensional visions but in laparoscopy two dimensional visions, as depth perception is lost.

4-In open surgery we are trained to use tactile sense and strength. We feel with our hands things that we cannot see with our eyes. There is no direct tactile perception in laparoscopy (3, 4).

5-In laparoscopy the ports are fixed, and the freedom of movements is lost. The movement of instruments are around a fulcrum which is the port of entry; it restricts the

movement of instruments to only 4 directions which are: rotation, up/down angulation, left/right angulation, in/out movement (3).

When the handle of instrument is moved to any direction the tip of instrument moves in opposite direction due to fulcrum effect, it makes hand eye coordination difficulty.

Due to decoupling of visual axis and motor axis and two-dimensional perceptions during laparoscopic knot tying a lot of extra movements are made, for example, over shooting of instruments, these imprecisions of movements can cause damage to patient's tissues by the tip of instruments during the attempts to perform a laparoscopic knot. Imprecision of movement happens more in hands of less experienced laparoscopic surgeons.

6-During laparoscopy the surgeon's movements are restricted, but all the muscles of arms shoulder, neck and back are activated and under tension, this causes lactic acid production in muscles and tendons and hence disabling muscle pain builds up, because of which the efficiency of surgeon reduces as the time of surgery increases (3, 5, 6). On the long run many surgeons have acquired permanent serious trauma such as headache (7), neck pain cervical spondylitis (7,8), shoulder pain, finger joint pain in hands, tenosynovitis and hand muscle injury due to performing multiple laparoscopic procedures where suturing and knotting were required (9,10).

7- Laparoscopic instruments work on reduced efficiency compared to laparotomy instruments. For example, the laparoscopic grasper transmits force with a ratio of only 1:3 from the handle to the tip as compared to 3:1 with the hand-held hemostat in open surgery. Hence, a laparoscopic surgeon must put in more effort for the similar results (11).

Some common laparoscopic knot tying technical difficulties: -

The laparoscopic knot tying is classified under extracorporeal and intracorporeal techniques. All these methods have been developed over many years since 1972, when laparoscopic suturing was introduced by H. Courtnay Clarke.

Techniques of intracorporeal knot tying such as expert 'c', Cinch, Smiley, Gladiator and Spaghetti techniques are aimed at forming a square knot, granny's knot or surgical knot as the base knot intracorporeally, followed by few reverse half hitches to secure it (12). Recently some new techniques also have been introduced for laparo-endoscopic single-site surgery LESS, such as D-loop (13). All these laparoscopic techniques aim to use the laparoscopic instruments to imitate surgeon's hands movement in knot tying.

There are also different extracorporeal knot tying techniques:

1-Non sliding (static) knots, which are used when surgeon wants to avoid suture sliding through tissue or anchoring device.

The major drawback of intracorporeal knot tying and non-sliding extracorporeal knot tying is that the loop may loosen before second throw is placed on first throw to secure it.

In extracorporeal non sliding knot tying, surgeon must note that if all the half hitches are made keeping the standing end on tension, the knot will have sliding property and is not locked safely. To achieve knot security the half hitches should be made on alternate posts or fastened by past pointing with knot-pusher to change the configuration of sliding knot to non-sliding knot.

2- Sliding or slip knots- which allow the knot to be tied extracorporeally and then it is slid on standing end, with a knot-pusher to the site where knot is to be applied. There are many types of slip knots such as: - Roeder knot, Duncan Knot, Nicky's knot, Weston knot, Meltzer knot, SMS knot, Tayside knot.

The main drawback of the sliding knot or slip knot tying technique is that its components should be stacked properly on the standing end otherwise its shape and configuration will change, as a result of this, either it will not slide on standing end or its loops are loose so they will form a faulty knot which does not have the property of intended slip knot. In addition, these loose knots allow more suture material to be left at surgical site causing more forging body reaction and increase chance of inflammation and infection. To make the proper configuration of slip knot using working end on the standing end using gloved hands during surgery needs a lot of practice and skill as both suture ends are thin, soft and highly mobile. In addition, gloved hands have less tactile sensation so these factors increase the chances of faulty sliding knot formation during laparoscopic extracorporeal knot tying.

Considering the ergonomic and technical difficulties in laparoscopic suturing and knot tying, we conducted a qualitative, explanatory research on bases of which we introduce a new technique of laparoscopic knot tying, aiming at:

1-Reducing the movement of instruments intracorporeally while knot tying in order to reduce chance of trauma to tissues close to site of knot application.

2- Suitability to ergonomics of laparoscopic operative surgery, so that there would be fewer traumas to surgeon.

3- Accurate Knot reproducibility, security and stability.

4-Reduce the amount of suture material used in knot, to decrease foreign body reaction in patient's tissues.

Basic principles of knot tying

Surgeons are taught that it is vital to perfect their technique of knot tying as within the strength of the knots lay the safety and lives of their patients. The important basic principles of achieving knots with correct configuration, appropriate shaping and maximum security and stability which are related to understanding knot tying techniques should be well understood. As Clifford W. Ashley says in his book of knots: "a knot is either perfect or hopelessly wrong, it is never nearly right".

Generally, the ***tied knot has three parts***: (Fig. 1)

1) Loop which embrace the tissue, vessel or the two edges of divided wound which needs to be approximated.

2) knot- the knot is composed of a number of throws or winds snugged against each other.

3) Ears- i) Needle-end or post limb of suture and ii) short limb or working limb

To understand the technique of knot tying we should know that to form an absolutely perfect knot we should concentrate in three ***stages of knot tying technique*** which are:

1- Configuration-

Configuration means the composition of different components of knot such as throws, winds and half hitches forming the knot.

To avoid foreign body reaction to suture material while knot tying, surgeon should choose the simplest knot configuration suitable for the situation; the knot must be as small as possible to minimize foreign body reaction, also consider using the smallest suture size necessary to achieve strong tissue approximation. The ears of knot should be cut as short as possible but not so short that knot can unravel.

Common knot tying terminology: -

Working end or running end or loop end - The distal end of suture away from the needle end. It is the active end that is used to form the knot on standing end. (Fig.2)
Standing end or post limb -The passive end of suture which is closer to needle end or at the other end of working end. (Fig.2)

Overhand or underhand knot/ throw- A throw is a wrapping of one strand around the standing end or around an instrument which act as the standing end, once; angle of the wrap is 360°. (Fig.3)
Overhand/overturn or underhand/under turn Loop -It is a full circle formed by passing the working end over or under itself. (Fig.4)
Overhand half hitch, refers to the working end forming an overturn loop around the standing part and then *pass over* working end.
Under hand hitch refers to the working end forming an under-turn loop around the standing part and then *pass over* working end. The half hitch can slide over standing part but it is not a secure knot by itself. (Fig.5)
Reverse half hitch- If the previous half hitch was over hand hitch, the reverse half hitch will be applied as under hand half hitch, and vice versa.
In a double throw or double wrap, the working end of a strand is passed twice around standing end; the angle of double-wrap is 720°. (Fig .6)
Bight/ turn/elbow- A U-shaped curve of suture, which the two ends do not cross over one another. (Fig.7)

2- Factors affecting shape of a knot are:

A) Tension applied on suture-

The shape of knot made by each person is different. It is just like individual signature. If you might have noticed, if two people use same knitting needle and same yarn and switch while knitting you can easily tell the shape of knots differ even though they have applied the same knots configuration, it is because of the difference in tension applied on the yarn for stacking each component of knot on previous component.(Fig.8)

In surgical term keeping the components of knot in order is called “stacking”. The tension applied by surgeon on each component of knot should be enough to make components of knot to stack appropriately. If excess tension is applied it might cause breaking of suture or cut the tissue. If less tension is applied while stacking, an insecure knot may form and in a surgical case, it may cause a catastrophe.

B) You might have noticed that in art of knitting, for different size threads different size needles or hooks are required. This is because if the size of the thread is not correct for diameter of the needle the knot will be too loose or too tight. If instruments are used to cast the components of knot on them, before making the knot, for example where hooks or knitting needles are used, the diameter of the instrument should be appropriate for size of suture. The general rule to make reasonably good knot is to have hooks or

instrument 2-3 times the thickness of the suture we use. (15) The bigger the diameter of instrument, the looser the knots especially if more than two throws are used. (Fig.9)

C) There is an important principle in one hand knot tying technique, “After tying the first half hitch, traction on standing end should be maintained to avoid loosening of loop before you make next throws”. After we finish each consecutive throw and sliding it down to the knot, we must put traction on both ends equally to changes the slip knot to flat knot configuration and hence its character from sliding to non-sliding. If this step to change the sliding configuration to non-sliding flat knot configuration is not done, the knot may slip on standing end and loosen. This is the principal used in past pointing when sliding half hitches are pushed with knot pusher, to stabilize and prevent the knot from slipping.

In laparoscopic knot tying it is important to understand the details of ***changes in configuration of knot by changing the traction force from one end to another end of the suture.***

Direction of traction force applied on each end of suture during knot tying, can bring about change in shape and geometry of knot:

i-Capsizing-Flat knot‘s geometry changes to slip knot geometry, for example overhand knot changes to half hitch by pulling one end(Fig.10).The flat knots used in laparoscopy can become slip knot if their capsized version is used, for example Taut Line hitch and Nicky’s knot are actually the capsized version of surgeons’ knot (16). (Fig.11)

ii-Flipping- Interchanging the traction between working end and standing part, relocate the knot from one end to the other. (Fig.12) In case of sliding knot made of half hitches, flipping changes the last half hitch position and make a reverse half hitch on alternating post. Flipping is useful in locking and securing the sliding knot.

3-securing-

The completed knot must be secure, with no chance of slipping. We have to consider the following points in securing the knot:

a) Type of suture material used in knot tying, influences knot security. The braided sutures create more friction than monofilament sutures, so there is less possibility of knot loosening in braided compared to monofilament suture. The number of reverse half hitches for securing knots made by monofilament suture material need to be more, to increase length of contact and complexity between suture limbs so as to achieve higher internal interference and more knot security. (14, 17, 18, 19)

b) Tightness and safety of knot also depends on the size of the suture, for example knots made of 2/0 suture is twice as tight as 3/0.

c) During laparotomy usually we use square knot and surgeons knot. We have learnt that applying few reverse half hitches will strengthen the security of the base knot. Some studies have shown, that under laboratory conditions, the ideal knot has 5 throws to maximize tensile strength and reduce the risk of untying. This finding does not seem to vary with the type of suture material. (20, 21, 22)

Most Studies have shown that addition of 3 RHAP in laparoscopic extracorporeal knotting, improves knot security of all slip knots. (14, 17, 18, 19)

d) After each throw is made, for shaping a flat knot, both suture ends should be pulled to opposite direction, parallel to loop of knot, to prevent the knot from forming capsized sliding character. In case of slip knots, past pointing with knot pusher will shape the half hitch into a flat knot.

e) To secure sliding knots, especially arthroscopic knots, 3 RHAP is made. Each half hitch should be secured by changing its shape from sliding to flat knot using knot pusher past-pointing technique. (14, 17, 21, 22)

Please note that, the number of additional half-hitches after 3 RHAP, not only will not increase the security of knot, but also it increases tissue foreign body reaction and knot failure due to material failure (breakage). (14, 17, 18, 19)

Innovative Radfar's technique of laparoscopic knot tying:

The Radfar's technique was inspired by knitting knot and fishing knot application techniques. This innovative technique of laparoscopic knot tying was tried several times in our lab using laparoscopic simulator, to make sure we can apply the laparoscopic knots with correct configuration; appropriate shaping and maximum security and stability.

Instruments needed for knot tying:

-2 Needle Holders

-Maryland grasper dissector

-Knot pusher

-An Artery forceps

-Laparoscopic scissors

-U-Hook loop thread guide or device in case of extracorporeal knot tying (Fig 13). We made a u-hook loop thread guide by bending the stylet of a spinal needle size25 from mid-point over itself. Thickness of the U-hook loop should be as close as possible to thickness of the suture used. If it is too thick the components of knot will be arranged very loosely on the standing end (faulty knot); if it is too thin, it cannot create enough space for the standing end to pass though the components of knot formed on it by the running end.

-Needle thread guide-Sterile injection needle with smallest bore diameter to allow the standing end of suture to pass through its cavity can be used.(Fig 14,15)If the needle is too thick the components of knot will be arranged very loosely on standing end (faulty knot); if it is too thin, the standing end cannot be passed through it so it cannot be used as a thread guide to pass standing end through the components of knot formed by the running end on it.

-Suture material

-Metal rod reducer (size 7mm) - it should accommodate needle holder of 5 mm shaft diameter and should pass through port cannula of 10 mm diameter. (Fig.29)

-Endoski needle is preferable. It is a needle which its proximal shaft of is 1.5 times the length of distal curved (1/4 of a circle) portion. (Fig. 16)

Radfar's Technique:

This technique is useful for intracorporeal and extracorporeal knot tying. We worked on this innovative technique for two years. We tried to examine tying various types of endoscopic knots with this new technique, in vitro, using laparoscopic simulator.

1-Extracorporeal knot tying by Radfar's Technique:

Basic steps:

In this technique working end or loop end of suture is casted on shaft of appropriate sized U-hook loop thread guide or a Needle thread guide, in form of capsized configuration of sliding/slip knot outside the body, the standing end is passed through the casted working end using thread guide, to form a sliding knot.

The capsized configuration of flat knots such as Square knot (Fig.17), Granny's knot (Fig.18), surgeon's knot (Fig.19), Granny wise Surgeon's knot/ Nicky's knot (20), Tennessee slider or What knot (Fig.21,22) which can be used as sliding knot are demonstrated diagrammatically and pictorially. The blue tube is used in pictures to

representing the guide (U-hook loop/needle guide) or standing end and the rope represents the running end / loop end/working end of suture which is casted on the guide. The arrow indicates the direction of entry of the standing end through the components of knot formed by running end.

Compound sliding knots can be divided into

1-Non-locking such as Duncan loop (Fig.23) which resists slipping by tightness of its wrappings of loop end around the post line. (14)

2- Proximal locking such as Nicky's knot (Fig.20)

3-Middle locking knot such as SMC Knot (Fig.24), Tennessee slider knot (Fig. 21,22). (14)

4-Distal locking such as Weston knot (Fig.25), Roeder knot (Fig.26), Meltzer knot (specially was designed by Meltzer for PDS suture) (Fig.27), Tayside knot (resistance to reverse slippage equivalent to surgeon's knot) (Fig.28). (14)

The figures show the capsized diagram of the knots and the practical casting of the loop or working end over the standing end; the blue tube is used in pictures to representing the guide (U-hook loop/needle guide) or standing end and the rope represents the running end / loop end/working end of suture which is casted on the guide.

The slip note is shaped and then slid on the standing end by knot pusher to the site where the knot is to be applied as base knot.To secure sliding knots, few RHAPs is applied over it. Each half hitch should be secured by changing its shape from sliding to flat knot using knot pusher by past-pointing technique. (14,17) In case of especially arthroscopic knots, to prevent sliding, usually 3 RHAP are thrown after the sliding knot, half hitches should be flipped to tighten, by past-pointing to prevent loosening of the knot. (14, 17)

The number of the reverse half hitches is decided according to the type of suture material, the type of base knot and the enforcement required in the particular situation by surgeon.

Advantage of this technique over the traditional extracorporeal knot tying technique, is that the components of knot are well stacked on the shaft of needle guide or U-hook loop guide. There is less chance of faulty knot formation, and as a result a well formed absolutely right knot can be formed. There is minimal foreign body tissue reaction as minimal amount of suture material remains in tissue in form of knot.

2-Intracorporeal knot tying by Radfar's Technique:

Basic steps:

A- Pass the needle holder into metal reducer, so as to prevent distortion of the suture casted on needle holder while passing through the entry port. (Fig. 29)

B- Casting the basic knot (Square knot, Graney's knot or surgeon's knot) configuration with working end of suture around the shaft of needle holder outside body. (Fig. 30)

C- To introduce the needle and suture, hold the needle end of suture, one cm away from needle with needle holder. In case you want to make a free tie around a structure, hold the standing end, one and half cm away from its end with needle holder. (Fig. 30)

D- Cover shaft of needle holder and needle suture complex within the metal reducer.

E- Introduce the metal reducer which is covering needle holder and suture within it, into the 10 mm cannula port.

F- After the needle is passed through the tissue (or in case of making a knot around continuous structure, when needle holder pass under the structure which should be tied) the Maryland (or another needle holder) is used to hold the needle or standing end and pull the suture, then the needle end or standing end is held with needle holder again and the casted knot configuration on short end or loop end is slipped over it by Maryland. (Fig.31)

G- By pulling the standing end the slip knot slides to the tissue and tighten.

H- Then steps for shaping and securing the knot are performed. This base knot is secured from loosening or dismantling by flipping which means interchanging the tension from needle end of suture (standing end) to the short distal end of suture or loop end or working end; this will ideally change the shape of the knot, from sliding to a flat knot. By changing shape of the knot, the property of knot changes from a sliding knot to a strong non-sliding knot which is more secure. Then both sides of suture are pulled with equal force horizontally in opposite direction, to further tighten the base knot and prevent it from slipping or loosening.

Throwing few reverse half hitches, on this base knot will guaranty the security of knot from slipping or unwinding. The number of the reverse half hitches is decided according to the type of suture material and type of knot applied in the particular situation, by the surgeon.

Innovative technique of applying various Knots used for intracorporeal knot tying:

1-Dundee jamming Knot:

This knot is used as starting knot in continuous suturing, where only the aim is to approximate the tissue but excess tension on tissue is not required, for example in peritoneal closure.

Take sufficient length of thread for intracorporeal suturing 20-25 cm.

Pass the needle holder into metal reducer, so as to prevent distortion of the suture casted on needle holder while passing through the entry port.

1-Make a loop, with the short end of suture passing under the long end of suture. (Fig.32)

2-Pull a loop of long end through this loop, tighten the first loop. The short end should be 1.5 to 2 cm, excess should be cut. (Fig. 33)

3-Pull a loop of long end through the first loop, tighten the second loop. Note that by pulling at the long needle end of the suture the loop can be tightened. (Fig .34)

4-Put needle holder shaft through the loop, tighten the loop around it, Hold the needle-end of suture about one cm away from needle, in such a way the concavity of needle faces up. (Fig 35) Cover shaft of needle holder and needle suture complex within the metal reducer. Introduce the metal reducer covering needle holder and suture within it into the port.

5-Within cavity the needle should be grasped properly by the needle holder, at its 1/3rd 2/3rd point and at an obtuse angle in relation to the needle holder with concavity facing up.

6-After passing the needle through the tissue, the needle is dropped, as a trailing needle cause less trauma to surrounding tissues, needle end is held with Maryland. Half of the suture is pulled through the tissue. Then the suture is grasped by the needle holder 1cm away from the needle and the short end of the suture is held by the Maryland and the Dundee jamming loop is pulled towards the tip of needle holder while needle holder pulls the needle through the loop. (Fig.36) As soon as the needle is through the loop, it is dropped, and rest of the suture is pulled through tissue by instrument to instrument technique, as we pull the suture the Dundee Jamming slip knot tightens. This knot is usually used as starter knot for continuous suturing.

2- Square Knot, Granny Knot and Surgeon knot:

Pass the needle holder into metal reducer, so as to prevent distortion of the suture casted on needle holder while passing through the entry port.

1-Make a loop with short end of suture passing under the long end (Fig.32)

2-Pull a loop of long end through this loop, tighten the first loop. The short end should be one and half to 2 cm, excess should be cut. (Fig.33)

3-Pass the needle holder through the loop and tighten the loop around the shaft of needle holder. This pre-tied loop acts as an anchor for the loops and turns of actual base knot which is to be casted on the shaft of needle holder. We can call this step as "anchoring pretied loop". (Fig 37)

4-At a distance of 5 cm from anchoring loop towards the tip of needle holder cast capsized Square knot (Fig.38)/ Granny knot or surgeon knot, as follows:

i) Capsized Square knot:-Two reverse half hitches one overhand and one underhand on shaft of needle holder as follows: hold the long end of suture between thumb and index finger and role it clockwise till a loop is formed cast it on the needle holder shaft then repeat the same process but this time make the loop by rolling the suture anticlockwise, cast the second loop on the needle holder shaft. (Fig.17)

Note: For casting Capsized Square knot always form two reverse half hitches i.e. Overhand(clockwise) + Underhand (anticlockwise) or vice versa.

ii) Capsized Granny knot: - the half hitches should be same type i.e. Over hand (clockwise) + Overhand (clockwise) or Underhand (anticlockwise) + Underhand (anticlockwise). (Fig.18)

iii) Capsized Surgeons Knot: - It is more secure than square knot as it offers more friction due to addition of one turn in first half hitch thus decreasing chances of unwinding, slipping or loosening of the knot. For casting this knot, first cast a square knot as explained before, then wind the long needle end of suture around the shaft of needle holder once between the two reverse half hitches, this wind should cross over the part of suture connecting the reverse half hitches. (Fig.19)

5-Hold the needle-end of suture about one cm away from needle in such a way that the concavity of needle faces up. Cover shaft of needle holder and needle suture complex within the metal reducer. Introduce the metal reducer covering needle holder and suture within it, into the port.

6-Within body cavity the needle should be grasped properly by the needle holder, at its $1/3^{rd}$ $2/3^{rd}$ point and at an obtuse angle in relation to the needle holder with concavity facing up.

6-After passing the needle through the tissue, the needle is dropped, as a trailing needle cause less trauma to surrounding tissues than a held needle when we pull the suture through tissue. Half of the suture is pulled through the tissue by Maryland. Then the suture is grasped by the needle holder 1cm away from the needle, with the help of the Maryland the casted loops on shaft of needle holder are pushed towards the tip over the needle. (Fig .39) Once the needle is pulled through the two half hitches, Maryland holds the needle end of suture, which is standing end carrying the slip knot over it. The needle holder is released from anchoring loop with help of Maryland; the anchoring loop is undone by pulling on short end of suture. The standing end is pulled under tension by needle holder while the Maryland helps to slide the slip knot on it to achieve the appropriate tissue approximation or tension in tissue held within the loop of knot. Once the knot is tightened, to secure it, the tension is shifted from standing end to short end of suture, by this we achieve flipping of the upper half hitch which causes the change of configuration of slip knot to non-sliding flat knot. The two suture ends are pulled in opposite directions parallel to the direction of knot's loop, to tighten the flat knot further. To further secure this knot one or two half hitches can be applied over it using the conventional intracorporeal knotting technique. After the knot is applied the short end and in case of interrupted suturing both ends are trimmed to about 1.5cm length.

This knot can be used:

1-For hemostasis

2-For tissue approximation

3-For tissue approximation under tension for example after myomectomy

4- For making a loop around a continuous structure, in which case sometime you do not require a needle on the suture so the standing end of suture is grasped with needle holder and passed under the continuous structure and then it is grasped by Maryland, the needle holder then traverses back from under the continuous structure and grasps the standing end of suture from the Maryland. The standing end is then pulled through the loops casted on shaft of needle holder (but not through the anchor loop) and the slip knot is guided to the tissue. The anchor loop is released from shaft of needle holder and opened by pulling the short end of suture. The standing end is pulled under tension by needle holder while the Maryland pushes the slip knot to achieve the appropriate

tissue approximation or tension in tissue held within the loop of the knot. Once the knot is tightened to secure it, the tension is shifted from standing end to short end of suture, by this we achieve flipping of the upper half hitch which causes the change of configuration of slip knot to locked flat knot. The two suture ends are pulled in opposite directions, parallel to loop of knot, to tighten the knot further. To further secure this knot one or two half hitches can be applied over it using the conventional intracorporeal knot tying technique. After the knot is applied the suture ends are trimmed to about 1.5cm length from the knot.

Discussion:

Radfar's laparoscopic knot tying technique is introduced taking into consideration:

The ergonomics of laparoscopic operative surgery- Since all the components of base knot are casted outside the body i.e. on needle holder for intracorporeal knot tying, there is no need to have the working instruments at 60 degrees or more while knot tying. Radfar's technique of knot tying is useful where working angle between working instruments is narrow and working area is limited, for example where the ports are place very close to one another or in single port laparoscopy and arthroscopy.

In addition, the time of intracorporeal knot tying is reduced as the base knot is already casted on needle holder. This technique of knot tying is user friendly to surgeon ergonomically; it is designed so that it reduces physical strains and trauma to the surgeon while operating laparoscopically.

Accurate Knot reproducibility-As the components of base knot are casted by working end on solid metal needle holder, U-hook loop or needle guide outside the body the components of knot can be reproduced faultless with proper slacking of the knot components on the guide and ultimately on standing end of suture. Also, after the knot is casted and guided on standing end, proper shaping stage assures knot accuracy before sliding it on standing end.

Knot security and stability- The major disadvantage of conventional intracorporeal square or surgeon's knot tying and non-sliding extracorporeal square base knot tying is that the loop may loosen before second throw is placed on first throw to secure it. By using Radfar's technique because first and second throw are simultaneously slid to the site were square or surgeon's knot should be tied, the knot is secured with first two throws so there is no chance of loop getting loose before RHAPs are placed for further securing the base knot.

Decrease trauma to patient tissues while applying knot-Due to decoupling of visual axis and motor axis and two dimensional perceptions during laparoscopic knot tying a lot of extra movements are made ,for example, over shooting of instruments, these imprecisions of movements can cause damage to patient's tissues by the tip of instruments during the attempts to perform a laparoscopic knot. Imprecision of movement happens more in hands of less experienced laparoscopic surgeons. By eliminating the steps of forming the first and second half hitches for making the basic knot intracorporeally using this method, the movement of instruments intracorporeally is minimized; hence reduce risk of trauma to patient tissues.

Decrease foreign body reaction in patient's tissues. Accurate knot formation by Radfar's technique reduces the amount of suture material used in the knot; this will decrease foreign body reaction in patient's tissues.

We find Radfar's technique fulfill our aim to achieve all the above.

We presume that Surgeons can master skill of laparoscopic knot-tying in shorter time if they use Radfar's technique because:

- It eliminates the conventional steps of forming the first and second half hitch for making the basic knot intracorporeally, because already first and second half hitches are casted on shaft of needle holder before introducing the suture in body cavity.
- The Surgeon is not worried for knot loosening between the application of first and second half hitch.
- Once the surgeon learns and practice how to cast various knots on shaft of needle holder accurately it becomes very easy and less time consuming to form a strong secure base knot during laparoscopic surgery.
- By learning the physics of how to apply the force on proper direction while knot tying, the perfect knot with exact shape and security can be achieved.

The knot chosen depends on surgeon's choice taking into consideration the situation and suture material used. Surgeon's knot provides the highest force to failure and the tightest loop circumference (14, 23). Surgeon's and square knot and Granny's knots can be used both in intracorporal knot tying and extracorporeal knot tying. It is straight forward for all surgeons to use the sliding surgical or square knots during laparoscopic surgery, as by experience in laparotomy operation we always use these knots for tissue approximation confidently, so the learning curve of laparoscopic knot tying becomes easier even for beginners. The amount of suture material used in square knot and

surgeon's knot is optimum, so foreign body reaction due to suture material used in knot after surgery is less than other complex slip knots used. We can secure them from sliding very easily by simply flipping the last throw by changing the pulling force on the loop end, and converting the sliding knot to flat knot shape by pulling standing end and loop end to opposite direction simultaneously, this maneuver locks and secures the knot. Few additional half hitches can be applied on the base knot for more security.

Conclusion:

Introducing a new Radfar's technique of laparoscopic knot tying taking into consideration:

-The ergonomics suitability to laparoscopic surgery

-Decrease trauma to surgeon while operating laparoscopically and on the long term reduce disability of surgeons due to trauma acquired after many laparoscopic surgeries.

-Decrease trauma to patient tissues while applying the knot

-Accurate Knot reproducibility, Knot security and stability

-Least amount of suture material used in knot, to decrease foreign body reaction in patient's tissues.

-Fast and easy learning curve for surgeons to learn laparoscopic knot tying.

Disclosure of Interests:

Authors have no conflicts of interest.

Contribution to authorship:

All authors have contributed equally in the acquisition and analysis and interpretation of data regarding various knot tying techniques. We have worked together on conception of new laparoscopic knot tying technique. Drafting and revising of work critically and final approval has been additional responsibility of corresponding author.

Ethics approval:

This is not a clinical trial study hence no ethical approval was necessary.

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