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Knot Security 101: A Comprehensive Practical Review to Optimal Knot Configuration, Pulling Direction, Throw Count, and Tail Length

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Background: Knots are the weakest structural point in a suture line and inevitably weaken almost all suture materials. This practical review critically evaluates the factors, such as suture material properties, gauge, configuration, throw count, and tail length, that affect knot security.

Methods: A PubMed search between the years 1934 and 2023 identified relevant studies that addressed factors relating to knot security. Studies that investigated knots and sutures solely used in laparoscopic and arthroscopic surgery were excluded. Knot configurations assessed were the Aberdeen, sliding, square, and surgeon's.

Results: Eighty-six articles were included in this review article and demonstrated that knot security varies greatly between suture materials and gauge. Knot security also varies by configuration, throw count, conditions, tail length, and stitch type. Throw count differs by knot configuration, with the Aberdeen knot being most secure with three throws and one to two turns compared with three to five throws for surgeon's and square knots. The optimal tail length was 3 mm.

Conclusions: This practical review demonstrates that there are significant differences in knot security based on a variety of factors. It is challenging to propose an ideal knot because most studies did not evaluate knot security using a broad variety of suture materials, gauges, and throws for each of the most common knots. Although this review article demonstrated several applicable findings, additional robust studies are needed to simplify proposals. *(Plast Reconstr Surg Glob Open 2024; 12:e6047; doi: 10.1097/GOX.0000000000006047; Published online 9 August 2024.)*

INTRODUCTION

Knot tying skills are foundational in surgery. Knots deform the suture and create a weak point.[1–3] Improper knot tying techniques coupled with tissues under tension can result in sutures breaking or unraveling.[4–9] Thus, insecure knots can promote dehiscence and impair wound healing. Given these potential ramifications, it is critical to identify factors that induce knot breakage and slippage.

To our knowledge, there are only five published systematic review articles on this topic.[10–14] Two of these reviews solely discussed knot security in oral and orthopedic surgery.[12,13] The systematic review and meta-analysis by Andryszczyk et al included only five studies and found considerable variations in knot security due to the suture properties, such as material and gauge. The article by Wong et al primarily addressed biomechanics but also included knots used in laparoscopic and arthroscopic procedures. Dinsmore's review article was published over two decades ago and assessed how knot configurations vary in strength, the variety of ways to measure such, and the need for nomenclature and standardized testing methods across studies. Although these articles addressed suture and knot biomechanics, none conducted a thorough comparison of throw count between materials and configurations. Additionally, none described how in vivo conditions affect integrity, proposed an optimal tail length, nor addressed whether the optimal pulling direction and knot type vary between interrupted and continuous sutures. This article

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aimed to provide a practical review of the primary factors that determine knot integrity and how to optimize these in plastic surgery.

METHODS

An electronic literature search identified relevant articles documented in PubMed between 1934 and December 2023. A thorough literature review was conducted with the assistance of a medical librarian affiliated with Michigan State University College of Human Medicine. The search strategy focused on biomechanical factors that affect suture integrity and knot security. The terms used to generate the search are demonstrated in Supplemental Digital Content 1. (**See table, Supplemental Digital Content 1,** which displays the PubMed search strategy. All results were sorted by publication date. **http://links.lww.com/PRSGO/D414.**)

Studies that investigated knot integrity and suture materials found solely in laparoscopic and arthroscopic surgery were excluded, as were studies not published in English. The titles and abstracts were screened to determine whether the studies met criteria, and the relevant articles were selected for review. The bibliographies of the included studies were also investigated for additional sources. Following study selection, one author extracted relevant study variables, such as knot configurations, throw count, suture material, and gauge. Other factors assessed included suture material properties and tail length.

RESULTS

Study Selection

A PubMed search yielded 783 publications, which were screened by title and abstract (Fig. 1). Of these, 110 relevant articles were selected for in-text review. Twenty-three articles were excluded due to being beyond the scope or related to the concept in a different manner. In total, 86 studies were included.[1–86]

Overview of Suture Materials and Properties

Sutures have likely been used since 50,000–30,000 B.C.E. to approximate tissues and support wound healing.[58] Cornelis Celsus in 50 C.E. described using braided sutures, likely linen or wool. In A.D. 150, Galen, surgeon to the gladiators, documented the use of silk and catgut to repair ruptured tendons.[58–60] Joseph Lister suspected that bacteria colonize suture strands, and thus began suture sterilization in 1867. Until synthetic sutures were developed in the 1960s, catgut was the most frequently used absorbable suture, and cotton and silk for nonabsorbable purposes.[60]

There are a variety of suture materials to select from with varying properties (Tables 1 and 2). Sutures are configured as either monofilament or multifilament. Compared with multifilaments, monofilaments exhibit less tissue drag, reactivity, and knot tie-down resistance.[22] Multifilaments are easier to cinch due to greater flexibility and less tendency to untie, but are more prone to bacteria colonization.[15,17,62,63] Multifilament sutures also produce larger knot volumes and swell more due to greater absorptive capacities and capillarity.[15,53] Tensile strength diminishes with degradation and is defined as the "weight required to break a suture divided by the suture's cross-sectional area."[15,59] All natural sutures are degraded enzymatically.[15,58–60] A suture is deemed absorbable if it loses 50% of its strength within 60 days.[15] Absorption rate also depends on tissue temperature and pH level.[17]

> **Takeaways**
>
> **Question:** What are factors that affect knot security?
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> **Findings:** Eighty-six articles were included in this review and demonstrated that knot security varies between suture material, gauge, configuration, throw count, tail length, and stitch type. Throw count also differed across knot configuration—AB knots are most secure with three throws and one to two turns compared with three to five throws for SU and SQ knots. Optimal tail length was 3 mm.
>
> **Meaning:** There are significant differences in knot security based on a variety of factors.

In 1937, the United States Pharmacopeia System (USP) was established to standardize suture sizes.[60] USP delegates a suture size based on a diameter range for a given tensile strength and not necessarily equate to caliber.[15,60] Suture size contributes to tissue reactivity and knot volume.[54,55] Knot configuration also relates to knot bulk, as sliding knots are volumetrically larger than square knots.[53] Although larger gauge suture exhibit greater strength, it contributes more foreign material and bulk.[54,64]

In the 1960s, synthetic absorbable polymer sutures were developed.[60] Contrary to natural sutures, synthetics are absorbed through hydrolysis and exhibit less tissue reactivity.[15] Synthetic sutures are also coated to further reduce tissue reactivity, improve handling properties, and add antibacterial elements.[65] Most synthetic absorbable sutures feature good tensile strength and low tissue reactivity (Table 1). Polyamide (nylon) (Monosof; Covidien, Minneapolis, Minn.) (Ethilon; Ethicon Inc., Somerville, N.J.), polybutester (Novafil; Covidien, Minneapolis, Minn.), polyester (Ti-Cron; Covidien, Minneapolis, Minn.) (Fiberwire, Mersilene; Ethicon Inc., Somerville, N.J.), polypropylene (Surgipro; Covidien, Minneapolis, Minn.) (Prolene, Ethicon Inc., Somerville, N.J.), and steel sutures are nonabsorbable, strong, and induce less tissue reactivity.

Compared with synthetics, natural sutures induce greater tissue reactivity. The first phase of a tissue reaction is mechanical due to passage of the needle and suture, followed by the second phase in which inflammatory cells infiltrate.[15] Prolonged tissue reactions impair healing by softening and weakening wounds. By measuring the density of inflammation and cells present, Sewell scoring helped grade tissue reactivity (Fig. 2).[61] First applied to gut sutures, Sewell grading determined that untreated gut sutures exhibit high reactivity. Silk, another natural suture, exhibits moderate tissue reactivity.[15,59] Silk is unique, as it induces a histiocytic response, which forms a fibrous capsule around the suture. Nonabsorbable sutures induce weaker inflammatory responses than absorbable sutures.[15] Other suture properties are further described in Table 2.

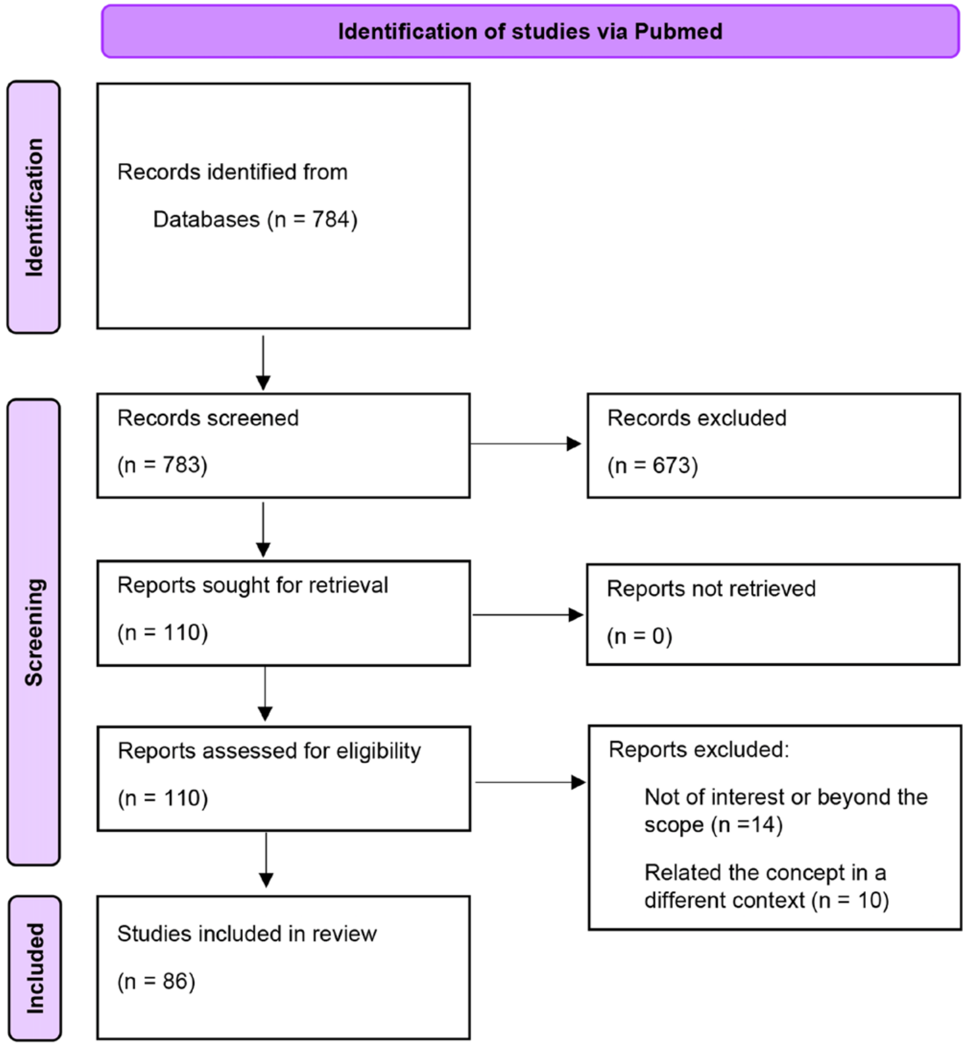

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

Knot Configuration

There are more than 250 knot configurations.[69] Tera and Aberg first described knot configuration notations (Fig. 3).[3] To assess knot security, a tensiometer measures "the maximum load sustained before ... knot slippage, knot failure, or suture ... breaking."[70] Except for polytetrafluoroethylene (PTFE; Gore-Tex, W. L. Gore & Associates Inc, Elkton, Md.), knots reduce a suture's effective tensile strength by one-third.[15,23] The most frequently used knots in plastic surgery are addressed in this section: Aberdeen (AB), sliding (S), square (SQ), and surgeon's (SU).

The main types of knot configurations are flat (granny, SQ, and SU), sliding (identical, nonidentical, and parallel), and self-locking (AB).[12,36,54,55] In flat knots, the suture strands are parallel. The SQ knot is formed by alternating throw directions and applying equal tension perpendicular to the knot's axis.[70,71] [**See Video 1 (online),** which displays an instrument tying a square knot.]

If tension is unequal, a half-hitch is configured.[70,71] Rotation of subsequent knots can be identical or not, yielding symmetric or asymmetric knots. An SU knot is a variation of a SQ or granny knot formed by double wrapping the first throw. [**See Video 2 (online),** which displays instrument tying a surgeon's knot.] An S knot is made with one axial strand held under tension. [**See Video 3 (online),** which displays an instrument tying a sliding knot.] The AB knot is a self-locking and terminating knot, designed to not be undone, and is formed by passing one loop through another loop.[44] [**See Video 4 (online),** which displays an instrument tying an Aberdeen knot.] Its namesake originated at Aberdeen University by Sir James Learmonth, who observed that it required less suture material than other knots.

Optimal Knot Configuration

Multiple studies found no significant difference in security between SQ and SU knots, whereas some elucidated discrepancies due to throw count and throw orientation. (**See table, Supplemental Digital Content 2,** which displays the optimal knot configuration. **http://links.lww.com/PRSGO/D415**.) One study determined that SQ knots were superior if formed from a loop, whereas SU knots were the best knot selection if only two to three

Table 1. Overview of Common Suture Materials

Material	Name (Covidien)	Name (Ethicon)	Configuration	Syn. versus Natural	Abs. versus Nonabs.	Tensile Strength	Tissue Reactivity
Surgical gut (chromic)	Chromic Gut		Multi	Natural	Abs	Poor (10–14 d)[15,16]	Moderate
Surgical gut (plain)	Plain Gut		Mono	Natural			High
Silk	Sofsilk	Perma-Hand Silk	Multi	Natural	Nonabs	High[18]	
Lactomer glycolide/lactide	Polysorb	-	Multi	Synthetic	Abs	Good (30% at 3 wk)[19]	Low
Glycomer 631	Biosyn	—	Mono	Synthetic		50% at 7 d[20]	
Poliglecaprone 25	—	Monocryl	Mono	Synthetic		7–14 d[15]	
Polydioxanone	—	PDS; PDSII	Mono	Synthetic		Good (50% at 2–3 wk)[15,21]	
Polyglyconate	Dexon	—	Multi	Synthetic			
	Maxon	—	Mono	Synthetic		6 wk[21]	
Polyglactin 910	—	Vicryl	Multi	Synthetic		Good (50% at 2–3 wk)[15,21]	
Polyamide (Nylon)	Dermalon; Monosof	Ethilon	Mono	Synthetic	Nonabs	High[15]	
	Surgilon	Nurolon	Multi				
Polybutester	Novafil Vascufil	—	Mono	Synthetic			
Polyester	Surgidac; Ti—Cron	Ethibond; FiberWire; Mersilene	Multi	Synthetic			Moderate
Polypropylene	Surgipro	Prolene	Mono	Synthetic			Low
Stainless steel	Steel		Both	Synthetic			

"Mono" indicates monofilament and "multi" indicates multifilament sutures. "Abs" and "nonabs" denote absorbable and nonabsorbable suture qualities.
Coated variations available.

Table 2. Suture Material Properties

Suture Properties		
Terms	**Definition**	**Examples and Notes**
Absorptive capacity	Rate at of suture degradation. A suture is deemed absorbable if it loses 50% of its strength within 60 d.[15]	Catgut sutures are rapidly absorbed by lysosomal proteases, typically as early as 12 h after implantation.[16] This quick degradation is associated with less tensile strength.
Capillarity	Tendency of fluid to be absorbed and transferred along a suture to the dry end.[15]	Greatest in linen and silk; least in polyester. Greater in multifilament sutures than monofilament. Also relates to absorption and bacteria transfer, as braided nylon absorbs up to three-times more bacteria than monofilament.
Coefficient of friction (μ)	$\mu = F/N$; the ratio of the frictional (F) force to normal (N) force. The ease at which a suture is pulled through tissues.[15,66] This value depends on material, surface characteristics, and tension.	Less in coated sutures than uncoated. However, coated sutures are more slippery and form insecure knots. Also greater in multifilament than monofilament sutures and in larger gauge sutures.
Configuration	Determined by the number of strands and orientation.	Multifilament (twisted and braided) and monofilament. Multifilament sutures are more flexible and easier to handle than monofilaments.
Gauge	Based on suture diameter range for a given tensile strength.[60] Delegated by USP to standardize sutures.	Larger gauge suture exhibits greater tensile strength but also contributes to tissue reaction and knot volume.[54,55] Larger suture increases tissue reaction to sheath volume by 255%. A two-times increase in gauge also increases knot volume by a factor of four to six.
Elasticity	Ability to regain its original length after stretch.[15]	A suture with greater elasticity has a tendency to cut into tissues, especially if swollen.
Memory	Ability to spring back to its native form and position.[15]	Monofilament nylon is more likely to untie, featuring great memory.[15,59] Silk has low memory.
Plasticity	Ability to retain a new length after stretch.[15]	Polypropylene exhibits great plasticity as it can maintain a stretch three times its length.[49] It is less likely to cut into tissues with swelling but can become loose once swelling decreases.[15]

throws are permitted.[4,24,27,36] These results also varied by suture materials as polydioxanone (PDS-II; Ethicon, Sommerville, N.J.) and polyglactin 910 (Vicryl; Ethicon, Sommerville, N.J.) were more stable as a triple-knot than SQ and SU knots. Throw orientation also altered security, as an SU knot with a forward-forward-reverse pattern was superior to a reverse (1 = 2 = 1) or one with a different pattern.[22] [**See Video 5 (online),** which displays an instrument tying a surgeon's knot (2 = 1 = 1) in a forward-forward-reverse pattern.] [**See Video 6 (online),** which displays an instrument tying a surgeon's knot (2 = 1 = 1) in a forward-reverse-forward pattern.] In studies that investigated the granny knot, it was never the most secure choice.[30,35]

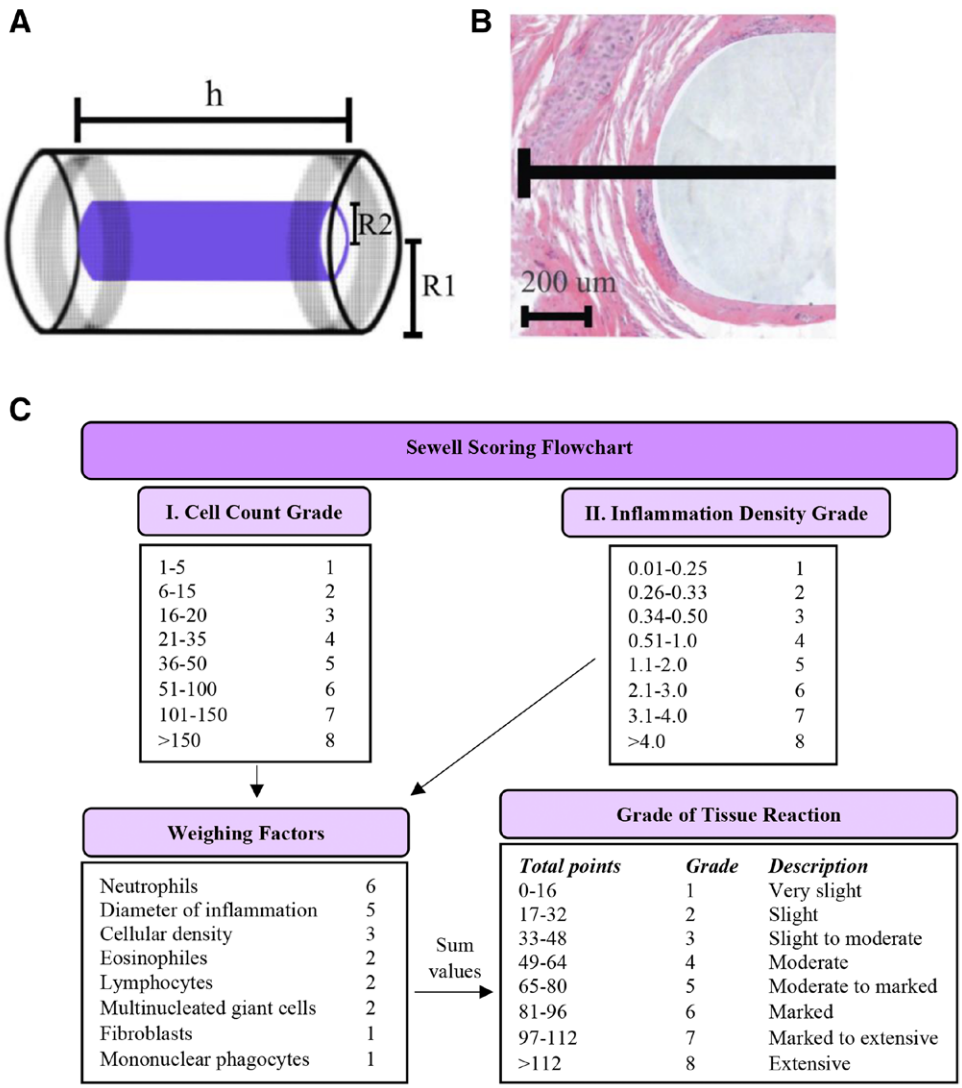

Fig. 2. Sewell scoring of sutures to grade tissue reactivity. Sewell Scoring involves microscopic analysis of sutures and the nearby tissues. The suture and its zone of inflammation are modeled as cylinders with volumes ($V = \pi r^2 h$). A, R1 is the radius of the zone of inflammation, whereas R2 is the suture radius. h is the embedded suture length. After the suture has been embedded, histological cross-sections (B) can be assessed microscopically. C, First, the number of inflammatory cells and their types are counted and assigned a grade. The density of inflammation is also measured within the powered field and graded. Both I and II grades are multiplied by their respective weighing factors. The sum of these values assigns an overall grade and description. Original artwork by Elizabeth Bushong, MD.

Several studies compared AB, SQ, and SU knots and deemed the AB knot as the smallest and strongest.[25,26] However, knot security did not differ between SQ and AB knots if the SQ knot received an additional throw.[29] Suture material also affected integrity of the AB knot because it was superior to SQ and SU knots using PDS-II but not nylon and polyglyconate (Maxon; Tyco Healthcare, Mansfield, Mass.).[24]

Of the studies that compared S knots, parallel outperformed nonidentical.[33] Babetty et al compared four types of S knots in dry and in vivo conditions using silk and nylon (Table 3).[32] Parallel alternating sliding (S//S//S//S) was the only configuration unreliable in both conditions. Comparing S knots by material and gauge, parallel alternating sliding knots with different patterns (S//S = S//S) was superior in silk across gauges and conditions. However, the nonidentical alternating knots with different patterns (SXS#SXS) was superior when using nylon in dry conditions and in vivo with 2-0 gauge.

Optimal knot configuration also varied by location in a closure.[42] The forwarder S and AB are self-locking knots frequently used to start and end continuous closures, respectively.[38,76,77] In a variety of materials and gauges, the forwarder and other self-locking knots outperformed both SQ and SU knots.[1,38,39] To terminate a closure, an AB knot was best.[40] Combined two throw SQ/AB knots were also more secure than S and SQ knots with two throws.[40]

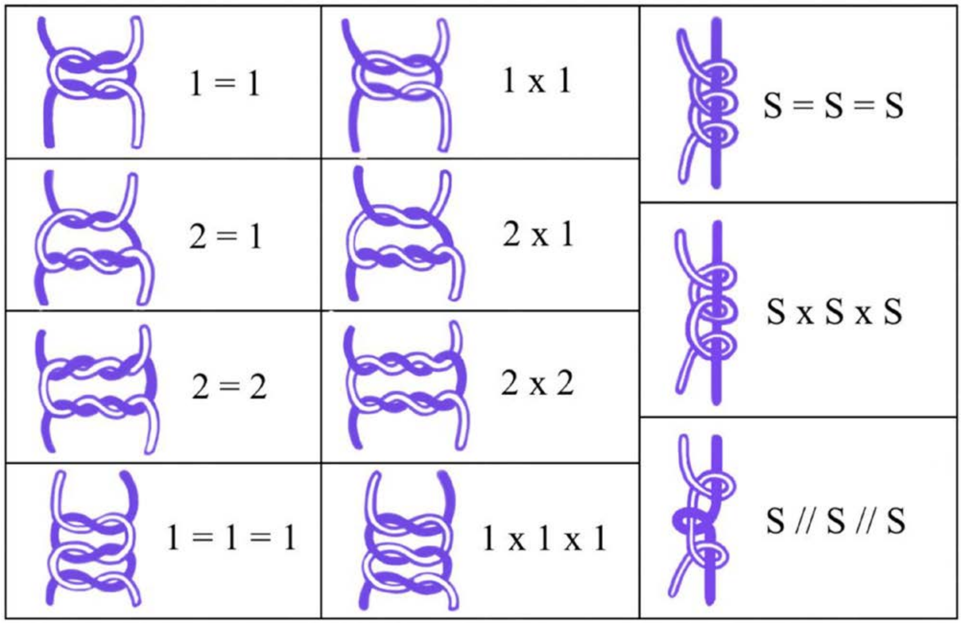

Fig. 3. Notation of common knot configurations. The knots diagrammed represent SQ (1 = 1), SU (2 = 1), granny (1 × 1), and S knots (S = S = S). Per knot configuration notation, the sequence of knots is read left to right. The digits signify the number of times the suture is wrapped per throw. "=" notation denotes throws in opposing directions, "X" nonidentical directions, and "//" parallel. Original artwork by Elizabeth Bushong, MD.

Table 3. Comparing Sliding Knots

		Nylon	Silk
Dry	2-0, 4-0	Nonidentical alternating knots with different patterns (**SXS#SXS**)	Parallel alternating with different patterns (**S = S//S = S**)
In vivo	2-0	Nonidentical alternating with different patterns (**SXS#SXS**)	Parallel alternating with different patterns (**S = S//S = S**)
	4-0	Parallel alternating with different patterns (**S = S//S = S**)	

Throw Count

This section describes the optimal throw count for the previously discuss configurations. (**See table, Supplemental Digital Content 3,** which displays the optimal throw count. **http://links.lww.com/PRSGO/D416**.)

The Aberdeen Knot

In 2002, The Royal College of Surgeons of England recommended an AB knot to consist of six throws.[75] However, Stott et al determined that only three throws are necessary if using PDS-II (#0).[44] Schaaf et al found similar findings with PDS-II (2-0), and recommended three throws with one to two turns.[43]

The Sliding Knot

Ivy et al compared the biomechanics of S knots in PDS-II and Vicryl (#0, 2-0) with three and six throws. Except for PDS-II (2-0), knot failure by untying was greater with three throws. Van Rijssel et al determined that five throws was sufficient for Dexon (#0) and Maxon (#0, 3-0). Modified identical S knots using PTFE required 10 throws, the most across all knots.

The Square Knot

Throw count also varied by material and gauge. Across studies, three throws were sufficient in chromic gut, Dexon, and polyester. The other coated and multifilament sutures, Vicryl, Polysorb and silk, exhibited heterogenous findings. With Vicryl, throw count varied from three to five.[37,48,53] Using smaller gauge suture, Polysorb required less throws, whereas silk required more. The only coated monofilaments investigated were polybutester and nylon, which were most stable with four and three to five throws, respectively. Uncoated monofilaments also varied from three to five throws. FiberWire and PTFE both required the most throws of six and seven, respectively.[23] Steels sutures only required two.[52]

Optimal throw count in SQ knots also varied by stitch type and location in a closure. Across materials and gauges, starting a continuous closure required one to three fewer throws than ending one.[47] And interrupted stitches with more stable with fewer throws than running sutures.[47]

The Surgeon's Knot

Overall, larger gauge suture required fewer throws. Dexon varied from four to five in #0 and 3-0 gauges, respectively. Multifilament polyglycolic acid (Dexon-Plus; Davis and Geck, Danbury, Conn.) was the only suture stable with two throws. Vicryl, another coated multifilament, required two additional throws when decreasing gauge from #1 to #0. However, Maxon required more throws with #0 than #1, with five and three throws, respectively. PDS-II and

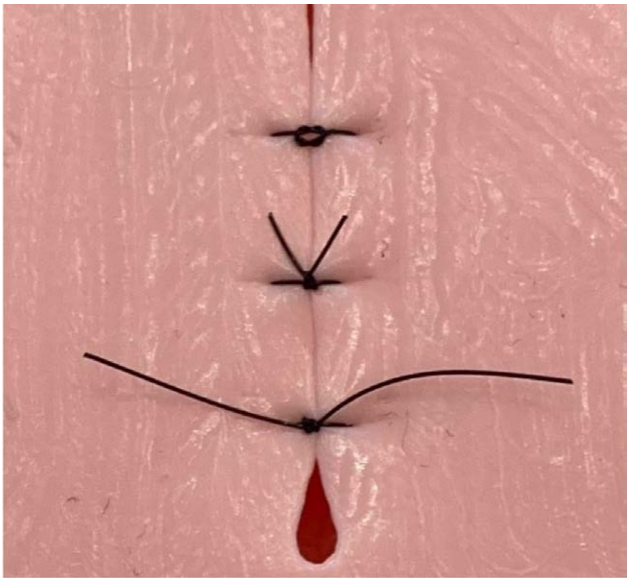

Fig. 4. Length of cut suture tails. From top to bottom, the cut suture tail lengths measure as 0mm, 3mm, and 10mm, featuring a 2-0 nylon suture (Ethilon; Ethicon Inc., Somerville, N.J.)

monofilament nylon required three to four throws across sizes, whereas PTFE required six. Of the sutures investigated, polypropylene was the only suture secure with three throws across sizes.

Suture Tail Length

Muffly et al conducted the only study on the relationship between tail length and knot security.[78] Using tail lengths of 0mm, 3mm, and 10mm, they found no difference in unraveling rates between 3-mm and 10-mm lengths (Fig. 4). However, knots without tails were 21.2-times more likely to unravel.

In Vivo Conditions

Knot security in vivo depends on a suture material's inherent degradation rate, pressure, location, and tissue conditions.[6,79–82] For example, sutures that approximate the anterior rectus sheath can withstand up to 97N (10.8 kp) of intraabdominal pressure before breaking.[6] Other in vivo factors that affected knot security include tissue holding power and dispersion of forces across the wound.[32] If tied too tightly, the tissues are strangulated, knot security reduced, and wound healing is impaired. In vivo, SQ knots also frequently take on a sliding conformation, particularly in monofilament sutures.[43,84] Akin to in vitro studies, AB knots in vivo are more secure than SQ and SU knots.

Instrumentation and Handling

The use of needle drivers or forceps damage and weaken suture.[64,85] Although Johnson et al found no difference, several studies determined that clamped monofilament sutures are damaged more than clamped multifilaments.[4,47,64,86] One study reported a reduction of 10% breaking strength if an SU knot was formed from a clamped monofilament. Clamping for only 15 seconds also markedly reduced the strength in monofilament nylon.[4,63] These effects were most prominent during instrument tying with needle drivers or forceps with teeth; however, damage also occurred with smooth jaws.[47,64,85]

DISCUSSION

There is not one ideal suture that possesses all characteristics to form an optimally secure knot applicable in every scenario; however, judicious selections can enhance security. Optimizing knot security often requires a tradeoff of one desirable property for another. The ideal suture architecture, size, and material depends on tissue tension and location. The results from this review article demonstrate that knot security heavily depends upon suture properties, gauge, and configuration. It is challenging to propose the "ideal" knot, as the studies in this review article varied greatly between those factors along with throw count, throw direction, and tail length.

Evidence conflicted when comparing knot security. (**See table, Supplemental Digital Content 4,** which displays the summary table for optimal knot configuration by suture material type. **http://links.lww.com/PRSGO/D417**.) Several studies that did find differences investigated larger gauge sutures used in equine surgery.[24–27] And when smaller sutures were used to compare flat and AB knots, there was either no difference or the results varied between studies.[22,23,27–30] However, most studies found AB knots superior to flat knots. As described earlier, S knots are a series of half-hitches configured from either granny or SQ knots.[11,31] When tension is applied unevenly across an SQ knot, it converts into two half-hitches. With tension, SQ knots irreversibly deform and tumble into half-hitches but originally intended half-hitches become tighter. S knots are useful in deep and narrow spaces, but most surgeons inadvertently create them.[33,53,70] Because of this, running sutures secured with SQ knots are only 50%–84% as strong as those formed with half-hitches.

The ideal suture material selection also varies by procedure and knot choice. For example, a braided polyester/monofilament polyethylene composite (FiberWire, Arthrex, Naples, Fla.) possesses low friction and high tensile strength, and thus, is optimal for tendon repairs as it permits movement within a pulley system without forming fibrous adhesions.[67] Additionally, nonidentical S knots formed from coated Lactomer glycolide/lactide copolymer (Polysorb; United States Surgical Corporation, Norwalk, Conn.) are very insecure and potentially unsafe.[35] In general, granny knots should also be avoided due to slippage.[3]

The orientation of a knot and its suture ends are also predicated by the pulling direction of the first loop. An SQ knot lies flat when pulled in alternate directions.[13] This forms a stronger knot than if pulled in constant directions. However, most resident surgeons pull in a constant direction and form an S instead of an SQ knot. The proper strand end orientation also differs between buried and surface knots.[13] To ensure the wound is best approximated and suture does not coil into the next stitch, surface knots should be formed by pulling the first loop perpendicular to the wound. To obliterate dead space and minimize suture tail length, a buried suture is optimally formed by pulling parallel to the wound.

The most harmonious finding between studies was that the optimal knot configuration depends on location along a closure. In running sutures, it is best to use a forwarder self-locking knot and terminate with an AB knot. Again, these findings were primarily investigated using large animal sutures, and thus, might not directly translate to humans. Terminating with an AB knot was also more secure than an SU knot, likely due to the deformation and weakening that double wrapping induces.

Studies that investigated throw count also featured broad gauge ranges. S knots slip instead of break, and thus require the most throws and form the bulkiest knots. SQ and SU knots are most secure with three to five throws, while the AB knot is most stable when formed from three throws and one to two turns. Therefore, to minimize knot bulk and potential tissue reactivity, it is best to minimize throw count in all knots other than S knots.

Before Joseph Lister began cutting suture tails short, sutures were left long and hanging outside the body.[58] The end of a tail must be cut short enough to minimize foreign material in the wound but not too short that it slips. Buried sutures require short lengths to prevent tissue reactivity and wound separation. Although other studies described consistently cutting tails to 3 mm, Muffly et al were the first to prove that this length provides the most secure knot with the least material.

Studies comparing conditions found that knot holding capacity is superior in vivo than in dry conditions.[39,79,81] Most knot security studies were done in vitro, reaffirming that those results should be consistent, if not superior, in practice. This is likely due to the lubricating nature of media that allows equal distribution of forces across a knot.[39] It is also no surprise that needle drivers or forceps can damage and weaken sutures.[64,85] Although one study found that clamping does affect suture elongation, it appears intuitive to minimize compression and shear forces on sutures during handling.

Limitations

This review only included studies available, reported, and published in English. Most of the studies included were in vitro in nature, and the few in vivo studies were in large animals. None of the articles executed a thorough analysis comparing knots robustly across configuration, knot type, material, gauge, throw count, and condition. Moreover, due to the lack of studies using smaller-gauge sutures, such as those in microsurgery, our findings might not be applicable to all procedures.

CONCLUSIONS

This practical review article demonstrates that there are significant differences in knot security. Although biomechanical studies were not done using all suture materials and gauges, these are generalizable recommendations that can better inform the knot tyer. It is necessary to pull parallel with the same force so as not to convert flat knots. All sutures should be cut with at least 3-mm tails. At least three throws are required with SQ and SU knots. In running sutures, it is best to start with a forwarder self-locking knot and terminate with an AB knot. Additional standardized studies that compare a variety of suture materials, gauges, and throw counts across all applicable knot configurations are warranted to provide a more thorough proposal for the optimal knot. Given the sparseness of studies comparing knot security in microsurgery vascular anastomoses, additional studies and practical review articles on the topic are warranted.

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DISCLOSURES

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