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# Poor knot security when closing running sutures with three threads

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## ABSTRACT

**Background:** Knot security varies with half-knot and half-hitch sequences, rotation sense, and the type and diameter of sutures.

**Objectives:** To evaluate the security of knots with three threads, as used for tying off running sutures.

**Methods:** Three-way randomised experiments, with a factorial design and 10 knots/cell. The first experiment evaluated the knot security of a surgical knot (H2H1sH1s) for single stitches (2 threads) or running sutures (3 threads), using polyglactin 910 or polydioxanone, of 2-0 or 1 diameter. The second experiment evaluated the knot security of a running suture with 4 or 5 half-hitch sequences and 2 or 3 blocking knots, using polyglactin 910 or polydioxanone, and with diameters of 2-0 or 1.

**Main Outcome Measures:** Knot security in Newton, measured with a digital dynamometer. With increasing forces, the knot either slipped open or blocked, causing the suture to break.

**Results:** In the first experiment, the knot security of surgical knots was less with monofilament ($P$=0.0004) and running sutures ($P$<0.0001), but not with suture diameter (three-way analysis of variance). Variability in outcome was greater with running sutures, especially with monofilament sutures of larger diameter. The second experiment demonstrated that half-hitch sequences occasionally opened with low forces, especially with larger monofilament sutures.

**Conclusions:** Compared to knots tied with two threads, knots with three threads have a lower and more variable knot security, especially with larger monofilament sutures.

**What is New?** Knots with 3 threads should be avoided, as they may occasionally open with forces below 30 or 10 Newton.

**Keywords:** Polyglactin, rotation, sutures, knot security, running suture

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## Introduction

In surgery, the choice of sutures and knots is based on tradition, experience, and knowledge. In the absence of documented forces required to keep tissues approximated, the choice of suture diameter and type is a clinical decision based on the estimated forces needed, the suture's tensile strength and resorption time, and surgical handling factors such as gliding. The choice of knots is guided by the estimated forces needed and knowledge of knot security. Knot security is the force (Newton) at which the knot either slides open or blocks, breaking the suture, and is measured with a dynamometer using progressively increasing forces.[1-5] Unfortunately, the forces required to maintain tissue approximation are poorly understood in gynaecological and abdominal surgery. Clinically, it is logical to postulate that these forces will vary between tissues and that the forces exerted on the abdominal fascia and on the promontory after sacrocolpopexy, especially during coughing, must be higher than after a bowel or vaginal cuff suturing. Instead of indicating the exact knot security in Newton, knots opening with forces <10, <30, and >30 Newtons were called clinically dangerous, insecure, and secure, respectively.[6,7]

Knot security in surgery increases with the tensile strength of the suture, correct and more sequences of half-knots (H) or half-hitches (S), more throws, correct rotation and stronger tying forces. Knot security is less with easily gliding monofilament sutures. Less understood is the occasional and poorly predictable reorganisation of knots during traction, resulting in a variable knot security, with occasionally dangerous knots opening with forces of a few Newtons.[6-9]

Knot security is reproducible and increases with the tensile strength of the suture, and with alternating the rotation of the same active end when making successive half-knots or half-hitches.[6-9] A similar rotation of 2 one-throw half-knots is known as a granny knot, and opposite rotation results in a flat square knot. The same holds for half-hitch sequences.[9] Sliding half-hitch (SS) sequences made with opposite rotation remain in one plane and squeeze the passive end symmetrically and more firmly. The surgeon should realise that for blocking half hitches, a similar rotation should be used, since inverting the active and passive ends has the same effect as changing the sense of rotation. Therefore, changing the active and passive ends, as done with bimanual suturing, also has the same effect as changing the sense of rotation. Knot security increases with the number of throws. With polyfilament sutures, secure knots (>30N) require 4 or 5 throws,[7] such as a 4-throw surgical knot (H2H1sH1s) or a two- or three-throw half-knot, followed by a two-throw half-knot (H3H2 or H2H2). Surprisingly, for H2H2 and H3H2 knots, rotation only marginally affects knot security, with similar rotation even being slightly better.[6,7] Secure half-hitch sequences require 5 or 6 throws, two SSs formed by alternate rotation, followed by two to four blocking half-hitches made by similar rotation.

Knot security is lower and more variable with easily gliding monofilament sutures, especially with larger diameters, which have less friction in the tissue and the knot. With monofilament sutures, knot security is low for most half-knot combinations, which should be avoided and replaced by six half hitches with four blocking knots.[8]

Less understood is that the security of individual knots can be variable and difficult to predict because of the occasional three dimensional (3D) reorganisation of the knot during traction. This reorganisation is more likely to happen when tying forces are low, with monofilament sutures and when half knots are destabilised by inadvertent traction on one suture end. For example, the asymmetric traction at one end of a flat square knot (H1H1s) risks transforming it into SSs, opening under forces of a few Newtons. This risk of inadvertent destabilisation increases when the surgeon is less experienced, the suture ends are short, or knot tying is more difficult because it is deeper or less accessible. The mechanism of reorganisation is a poorly understood random effect, and the mechanism is challenging to study, since 40 knots are needed to detect 5% less secure knots.[6,7] This 3D reorganisation explains that knot security can be unexpectedly and unpredictably low, resulting occasionally in knots opening with forces of a few Newtons.[6]

Knots used to finish a running suture contain three threads instead of two when tying single stitches (Figure 1). Surprisingly, knot security of knots made with 3 threads has not been investigated. Realising the lower and more variable knot security with monofilament sutures, and the recommendation to use 6 half-hitch sequences for monofilament sutures, we evaluated knot security with 3 threads, as used when ending a running suture.

## Methods

### *Terminology and Testing of Knots*

Terminology and testing of knots were described in detail previously.[6-8,10] Knots are defined by their type, an "H" for half-knots or "S" for half-hitches, followed by the number of throws and the rotation of the active end in comparison with the previous knot ("s" for symmetric knots in one plane resulting from alternate rotation and "a" for asymmetric knots after similar rotation). For half-hitches, it is necessary to indicate whether the knot is sliding "s" or blocking "b". For half-hitches, the number of throws and the "s" of sliding are omitted as they are always one, and to avoid confusion with the s of symmetric, respectively. For example, H2H1sH1s is a surgical knot with a 2-throw half knot followed by two 1-throw symmetrical half-knots. SSsSabSab means a second symmetrical and SS (made by alternate rotation) followed by two half-hitches, made by similar rotation, becoming asymmetric and blocking after changing active and passive ends.

Knots were made as described[11] by tying a suture around a 15-mm plastic tube. To simulate knot tying when ending a running suture, a loop of one of the suture ends (i.e., two threads instead of one) was tied to the other end (Figures 1 and 2). After knot tying, the suture threads were cut to 10 mm, allowing evaluation of any sliding. The loops were mounted on the hooks of a digital dynamometer (Sauter FH 500) and tested at a speed of 200 mm/min. With increasing forces, the knot combination either slipped open, or slid before blocking, or blocked, causing the suture to break. The endpoint is thus the force (N) at which the knot slips open or breaks. Testing was done at the Research Educational Centre of Turin University.


**Figure 1.** Half-knots with two (left) and three (right) threads as used to secure a running suture. The flat square knot with 3 threads is bulky, squeezing the threads less, which explains why they are less stable.

### *Experiments*

The experiments were designed to evaluate the knot security of knots made with 3 threads (as used for running sutures) of monofilament sutures, since with 2 threads, the knot security of half-knots was low and poorly predictable, and, therefore, 5 or 6 half-hitches with 3 or 4 blocking sequences were recommended. In a first experiment, the knot security of a surgical knot (H2H1sH1s) was evaluated with a 3-way randomised factorial design with 10 knots/cell comparing a 2- and 3-thread knot, a polyfilament (polyglactin 910 or Vicryl, Ethicon) and a monofilament (polydioxanone or PDS II, Ethicon) suture and 2 diameters of 2-0 or 1. The second experiment similarly evaluated knot security with 3 threads using 4 or 5 half-hitch sequences with 2 or 3 blocking knots, with polyglactin 910 or polydioxanone, and diameters of 2-0 or 1. In these experiments, the double thread was used as the passive thread for the first 2 sliding half hitches. Exploratory experiments had not shown a difference between SSsSabSab knots made between a single or double thread as the passive thread.

The two endpoints of these experiments were the knot security in Newton, and the number of knots sliding open with forces less than 30 Newton, considered insecure, as an indication of reorganisation, poor predictability, and a potential surgical risk.

All knots were made by the same experienced person (AR), under close supervision by MG to detect any mistakes. For each experiment, knots were block-randomised, i.e., for

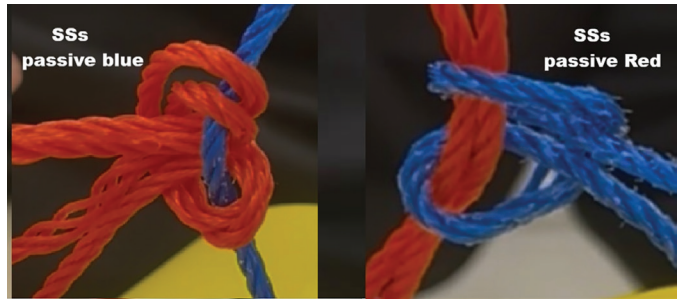


**Figure 2.** Half-hitch sequences with 3 threads are more bulky. Knot security of 4 and 5 half-hitch sequences with 2 (SSsSabSab) or 3 (SssSabSabSab) blocking knots was similar whether 2 or 1 thread was used as the passive thread for the first 2 sliding sequences. SS: Sliding half-hitch.

each combination, 1 knot was made before starting the second series.

Institutional Review Board (IRB) approval was not required for *in vitro* experiments that did not involve humans or animals, as previously confirmed in writing by the IRB at Leuven University.[6,8,9]

### *Statistical Analysis*

Statistical analysis was performed using SAS,[12] and means and standard deviation are reported unless otherwise indicated. The first experiment compared a surgical knot with 2 or 3 threads, two diameters, and two types of sutures. The second experiment compared 4 or 5 half-hitches, two diameters, and two types of sutures. Analysis was performed using a 3-way analysis of variance (PROC GLM) rather than logistic regression, since the endpoint (Newton of opening or breaking) is a continuous variable. A 3-way factorial design with 10 knots/cell was chosen because it yields statistical power of 80 knots per variable, which is similar to performing 3 separate 80-knot trials for each variable. The 3-way factorial design, in addition, permits the evaluation of an eventual interaction between the variables.[13]

## Results

In the first experiment (Figure 3), a 3-way analysis of variance showed that the knot security of a surgical knot (H2H1sH1s) was less with running sutures ($P<0.0001$) and with monofilament sutures ($P=0.0004$) but not with suture diameters. The results confirmed that, with polyfilament sutures, all surgical knots (H2H1sH1s) were secure, except one knot with 4 threads and a larger suture diameter, which slid open, although still secure at >50N. With monofilament sutures, knot security was more variable, and with 2-thread knots, 0/10 and 6/10, and with 3-thread knots, 1/10 and 7/10 of the 2.0 and 1-diameter sutures, slid open, with two 4-thread knots opening at <30N.

A 3-way analysis of variance of the second experiment (Figure 4) confirmed that knot security was less for 4-thread knots ($P<0.0001$), with monofilament sutures ($P<0.0001$), and with 4 half-hitches ($P<0.0001$). This experiment also confirmed that with monofilament sutures, 5 half-hitches with 3 blocking sequences resulted in 100% secure knots, whereas 4 half-hitches with 2 blocking sequences slid open in 6/10 and 7/10 of the 2-0 and 1-diameter sutures. More impressive was the number of sutures opening a less than 30N: with polyfilament sutures in 5/20 of the 4 half hitches knots, but with monofilament sutures in 10/20 and 4/20 of the 4 and 5 half hitches, respectively.

## Discussion

### *Main Findings*

These experiments demonstrate that the knot security is less for 3-thread knots than for 2-thread knots. With polyfilament sutures, surgical knots (H2H1sH1s) and 5 half-hitch knots with 3 blocking sequences (SssSabSabSab) are safe. The occasional (10%) 4-hitch sequence sliding

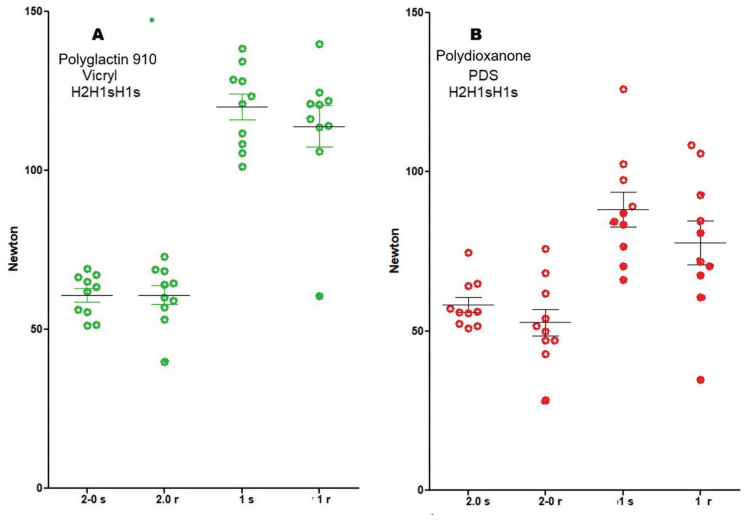


**Figure 3.** Knot security of a surgical knot (H2H1sH1s) using a polyfilament (polyglactin 910, green) or monofilament (polydioxanone, red) suture, diameter 2-0 or 1 when tied with two threads (s for single stitch) or three threads (r for running suture), as used in single stitches or running sutures, respectively. Open circles indicate knots that break, and filled circles indicate knots that slide open. Mean and SEM are shown. SEM: Standard error of the mean, PDS: Polydioxanone suture.

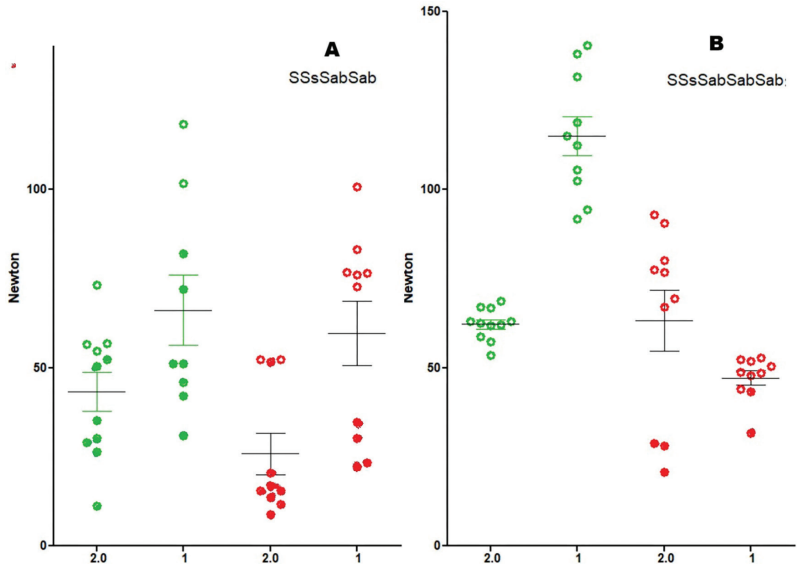


**Figure 4.** Knot security of polyglactin 910 (green) and polydioxanone (red) with a diameter of 2-0 or 1, to secure a running suture with 3 threads, using 4 or 5 Half-hitches, SSsSabSab or SSsSabSabSab, vicryl (green) or Polydioxanone (red) with diameters 2-0 or 1. Open circles indicate knots that break, and filled circles indicate knots that slide open. Mean and SEM are shown. SEM: Standard error of the mean.

open at a force >30N is probably not clinically significant. However, with monofilament sutures, knot security is lower and more variable, and many slide open,[8] with some 10% at forces below 30N or 10N. Also, with 5 half-hitch knots and 3 blocking sequences, knot security with 3 threads can be poor and 4/20 knots opened at less than 30N.

### *Strengths and Limitations*

The lower knot security with 3 threads in comparison with 2 threads is statistically solid ($P<0.0001$ and a power of N=80), and not surprising, given the more bulky nature of these knots, squeezing less the opposing threads (Figure 2). However, these data do not permit understanding why only some knots are less secure.

### *Strengths and Limitations Compared to Other Studies*

These data extend and confirm previous observations on knot security with 2 threads. Knot security is inherently variable, with knots occasionally opening with little force. The risk is lower with polyfilament than with monofilament sutures, and the variability emphasises the importance of making knots with correct sequences, rotation, and tying forces, avoiding destabilising knots and risking reorganisation.

### *Clinical and Policy Implications*

The surgeon should realise that these *in vitro* studies showing lower knot security with 3 threads underestimate the clinical risk, since they reflect knots performed by dedicated experts under visual control of the accuracy of sequences and rotation. During surgery, the risk of minor mistakes is higher, and knots risk being tied with insufficient force, incorrect rotation, and half knots risk destabilisation by inadvertently pulling one end, which occurs more frequently when less experienced surgeons tie knots with short sutures.

The clinical implications of the lower knot security of 3-thread knots are unclear and challenging to investigate. Since knots opening at low forces are rather rare, clinical series will be prohibitively large. In addition, the *in vivo* forces acting on the knots are poorly known. Therefore, clinical implications are speculative today. However, recognising the risk of knots opening unexpectedly with low forces, suggests that some rare complications of running sutures, such as vaginal dehiscence after hysterectomy or problems after vertical fascia closure, could be a consequence of insecure knots. It could be speculated that asymmetric niches following a C-section closed with running sutures might result from (monofilament) 3 thread knots sliding or opening with little forces.[14-16]

### *Unanswered Questions and Future Research*

The clinical consequences of variable and unpredictably low knot security after closing a running suture with 3 threads remain to be demonstrated. However, when

closing monofilament running sutures, it might be wise to avoid the risk by adding another single stitch and tying a knot with 2 threads between the end of the running suture and the passive end of the single stitch made with half hitches.

## Conclusion

To end a running suture such as a C-section or the fascia of a vertical abdominal incision, the risk of a low-knot security should be considered, especially when using monofilament sutures. It is suggested to avoid half-knot sequences and to use another stitch and tie the end of the additional stitch to the end of the running suture.

Understanding knot security will help the surgeon avoid small mistakes that cumulatively affect it. Examples are tying knots with short ends with the risk of destabilising half-knots, failing to respect rotation, being in a hurry and tying knots with insufficient force for a short time, or using half-knots for monofilament sutures. In surgery, the devil is in the sum of many details, and understanding helps to prevent mistakes.

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**Ethical approval:** Institutional Review Board (IRB) approval was not required for *in vitro* experiments that did not involve humans or animals, as previously confirmed in writing by the IRB at Leuven University.

**Informed consent:** Not applicable.

**Data sharing:** All data will be available upon simple request.

**Transparency:** The manuscript is an honest, accurate, and transparent account of the study being reported. No important aspects of the study have been omitted and all discrepancies from the study as planned have been explained.

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