The constrictor knot is the best ligature

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ABSTRACT

INTRODUCTION An ideal ligature should tighten readily and remain tight. Ligature failure can be a critical complication of invasive procedures in human and veterinary surgical practice. Previous studies have tested various knots but not the constrictor knot.

METHODS A new test bench was employed to compare six ligatures using four suture materials. As tension in a ligature is not readily measured, the study employed a surrogate measurement: the force required to slide a ligature along a rod. Benchmark values tested each suture material wrapped around the rod to establish the ratio between this force and the ligature tension for each material. Each ligature was tested first during tightening and then again afterwards. The benchmark ratios were employed to calculate the tensions to evaluate which ligature and which suture material retained tension best.

RESULTS The model provided consistent linear relationships between the tension in the suture and the force required to pull the ligature along the rod. The constrictor knot retained tension in the ligature best (55–107% better than the next best ligature). Among the suture materials, polydioxanone had the greatest ability to retain the tension in a ligature and polyglactin the least.

CONCLUSIONS The constrictor knot showed superior characteristics for use as a ligature, and should be introduced into teaching and clinical practice for human and veterinary surgery. The new test bench is recommended for future testing of ligatures as well as objective comparison of suture materials.

KEYWORDS

Surgical procedures – Operative – Ligation – Sutures

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Ligature failures are reported, sometimes with critical consequences (eg after pulmonary resection and laparoscopic cholecystectomy in humans, or following pedicle ligation in canine or equine hysterectomy).¹⁻⁴ This study examined the ability of a ligature to be tightened and then remain tight. In practice, ligatures are locked with additional overhand knots. Despite this, slipping may occur prior to the addition of the lock, particularly during an instrument tie. This critical risk was the subject of this study.

In the knotting world, the constrictor knot is the preeminent binding knot.⁵⁻⁶ Ligature techniques have been compared⁷⁻⁸ and new knots have been described.⁹⁻¹⁰ Leitch et al bench tested several knots for their ability to attenuate flow through a plastic tube.¹¹ However, these studies all considered the completed knot. We found no study that examined either the constrictor knot or the stability of the critical first part of a ligature knot. This study evaluated the constrictor knot for use in surgery and compared it with other ligature knots.

Before this study was initiated, one of the authors (HT) tested the constrictor knot’s ability to restrict flow in plastic tubing and also used it as a ligature for such procedures as pedicle ligation in canine ovariohysterectomy. To test the properties of a constrictor knot, he designed a horizontal test bench to measure the force required to pull a rod through a ligature, using friction as an indirect measure of tension.

Methods

Four suture materials (all manufactured by Ethicon [Somerville, NJ, US]) were tested: polypropylene (Prolene⁶), polyglactin (Vicryl⁶), polydioxanone (PDS⁶) and poliglecaprone (Monocryl⁶). All were size 3/0 (0.2mm) and all were within five years of their expiry date. A previous study had demonstrated that age has minimal impact on the properties of suture materials even ten years after the expiry date.¹²

The constrictor knot and five other ligatures were tested (Fig 1). Each was tied around a vertical smooth steel rod. The peak force required to start the ligature slipping down the rod was recorded, first with a standard weight on the suture material and then again after the weight was released. Measurements were made using a certified precalibrated S-beam load cell (RAS1, Loadstar Sensors, Fremont, CA, US) connected to single channel LoadVUE software (Loadstar Sensors) calibrated in newtons.
Preparation

The test bench, a modification of the original design, was constructed using an old Zyliss® workshop vice with various parts from a number 10 Meccano® erector set (Calais, France) (Fig 2). The vice was mounted vertically with the fixed jaw at the top. This jaw supported the load cell, from which hung the test rod, a length of mild steel Meccano® shaft (diameter 4.04mm).

The moving jaw was mounted below. A hole drilled in the jaw was centred under the load cell. The rod hung freely in this hole and through a closely fitting washer beneath. Two small pulley wheels were mounted on either side.

A load distributing frame hung beneath the lower jaw. A length of cord was passed around large pulleys on either side of the frame and then upwards to be attached to the ends of the suture material. The cord and suture material were exactly vertical.

The load cell was employed to prepare bottles of water as standard weights. The first weighed 10N with the frame. The second and third bottles each weighed 10N, thereby making it possible to apply incremental loads of 10N, 20N, and 30N.

Procedure

The selected suture material was threaded over one small pulley, knotted around the rod below the washer using the test ligature and then threaded over the other small pulley. Each end hung down and was knotted securely to the cord of the load distributing frame, creating a circular loop of suture material and cord. After each test, this loop was rotated slightly around the four pulleys to test a fresh portion of the suture material.

With the knot in place and no load on the suture material, the tare weight for the load cell was set to zero. The prepared weight was then suspended from the frame, taking care to avoid any shock load or pendulum movement. The load cell was set to record and the vice handle was rotated to lower the jaw at a rate of about 0.05mm/sec. The measured force increased steadily until the ligature slipped. This peak force was recorded and the load cell reset to zero.

The load distributing frame was then raised and supported, releasing all tension on the suture material. After at least 30 seconds, recording was restarted and the handle was rotated. Again, the peak force was recorded and the load cell reset to zero. The ligature was then retied using a fresh section of suture material, and the sequence was repeated several times for each combination of ligature and suture material.

Benchmark tests

Each length of suture material was wrapped twice around the rod, and weights of 10N, 20N and 30N were hung from the frame to apply loads of 5N, 10N and 15N to each end of the suture material. For each combination of suture material and load, ten values were averaged to establish the characteristic friction ratio (peak force/load).

Ligature tests

For the ligature tests, a 30N weight provided a load of 15N to each end of the suture material. Each ligature was tested five times to obtain an average value for the peak force required to move the ligature, first while loaded and then again after the load was removed. The friction ratio obtained in the benchmark tests was employed to derive the tension in the ligature from the measured peak force.

Ligature knots

The constrictor knot is like a clove hitch except that the two ends form an overhand knot under the overriding turn.5,6 Many methods are described to tie it. Several methods more suited for surgery are described in detail on http://www.animatedknots.com/indexsurgical.php.
The ligatures selected for comparison in this study are shown in Figure 1. They included:

> the constrictor knot (a binding knot using an overriding turn across the overhand knot)
> the surgeon’s knot (a double overhand half knot with a single turn around the rod)
> the modified surgeon’s knot (a double overhand half knot with a double turn around the rod)
> the single-double other side (SDOS) knot (a single overhand on one side and a double overhand on the other side)11
> the strangle knot (a binding knot using an overriding turn aligned to the overhand knot)10
> the modified miller’s knot (a strangle knot with the overriding turn to one side)

Results

Benchmark tests

The regression lines for the friction ratio slopes constrained to pass through the origin were essentially linear with $R^2$ values better than 0.992 (Table 1). Three suture materials had similar friction ratios around 0.86. The friction ratio for poliglecaprone was about 40% greater (1.228). These values were used to derive the tension in the ligature tests.

Ligatures

Comparison with the 15N weight shows how well each ligature could be tightened (Table 2 and Figure 3) and then how well it stayed tight (Table 3 and Figure 4). The highest ligature tension with the weight applied occurred with the strangle knot (51–75%) and the modified miller’s knot.

| Table 1 | Benchmark force (N) required to move the rod for loads of 5N, 10N and 15N employing two turns of suture material, with slope of friction ratio and $R^2$ values for regression lines passing through the origin |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Polypropylene   | Polyglactin     | Polydioxanone   | Poliglecaprone  |
| 5N              | 4.78 ±0.13      | 4.65 ±0.15      | 4.78 ±0.25      | 6.27 ±0.19      |
| 10N             | 8.35 ±0.08      | 8.63 ±0.25      | 9.13 ±0.32      | 12.15 ±0.20     |
| 15N             | 12.55 ±0.27     | 12.69 ±0.17     | 12.88 ±0.27     | 18.47 ±0.37     |
| Slope           | 0.845           | 0.857           | 0.881           | 1.228           |
| $R^2$           | 0.9961          | 0.9982          | 0.9962          | 0.9998          |

| Table 2 | Ligature tension (N) while the load was applied. Compare values with the 15N load used to tighten the ligatures. See Figure 3. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Polypropylene   | Polyglactin     | Polydioxanone   | Poliglecaprone  |
| Constrictor knot| 9.48 ±0.19      | 9.66 ±0.22      | 7.57 ±0.12      | 6.90 ±0.24      |
| Surgeon’s knot  | 4.43 ±0.13      | 5.02 ±0.19      | 3.28 ±0.13      | 3.82 ±0.15      |
| Modified surgeon’s knot | 7.63 ±0.20 | 6.95 ±0.58 | 4.62 ±0.27 | 5.48 ±0.29 |
| Single-double other side knot | 6.66 ±0.28 | 6.38 ±0.31 | 4.27 ±0.15 | 4.20 ±0.40 |
| Strangle knot   | 11.30 ±0.44     | 11.22 ±0.35     | 7.66 ±0.25      | 8.09 ±0.25      |
| Modified miller’s knot | 10.63 ±0.16 | 10.85 ±0.23 | 7.70 ±0.16 | 7.86 ±0.40 |

| Table 3 | Ligature tension (N) retained after the load was removed. Compare values with the 15N load used to tighten the ligatures. See Figure 4. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Polypropylene   | Polyglactin     | Polydioxanone   | Poliglecaprone  |
| Constrictor knot| 4.54 ±0.24      | 2.63 ±0.17      | 5.63 ±0.08      | 4.29 ±0.31      |
| Surgeon’s knot  | 0.51 ±0.03      | 0.10 ±0.03      | 1.42 ±0.10      | 0.31 ±0.02      |
| Modified surgeon’s knot | 2.19 ±0.51 | 0.93 ±0.11 | 3.32 ±0.16 | 2.76 ±0.32 |
| Single-double other side knot | 1.45 ±0.11 | 1.44 ±0.20 | 3.37 ±0.11 | 1.82 ±0.13 |
| Strangle knot   | 0.54 ±0.15      | 0.39 ±0.07      | 0.53 ±0.08      | 1.48 ±0.21      |
| Modified miller’s knot | 0.31 ±0.08 | 0.38 ±0.13 | 0.29 ±0.03 | 0.69 ±0.19 |
(51–72%), followed by the constrictor knot (46–63%). The other three ligatures tightened less well.

The constrictor knot showed the highest ligature tension after the weight was removed (between 55% and 107% greater than the next best) (Table 3 and Fig 4). After each test, it remained tight and was harder to release than any other ligature. The modified miller’s knot, the strangle knot and the surgeon’s knot retained tension poorly.

Suture materials
The suture material used affected the behaviour of the ligatures (Tables 2 and 3). Ligatures employing polydioxanone tended to have lower ligature tensions while the weight was applied but retained tension well (eg 74% for the constrictor knot). By contrast, ligatures employing polyglactin had higher ligature tensions while the weight was applied but retained tension poorly (eg only 27% for the constrictor knot).

Discussion
Ligatures
The strangle knot, modified miller’s knot and constrictor knot all tightened readily. The three that did not (the surgeon’s knot, the modified surgeon’s knot and the SDOS knot) all incorporate a double overhand intended to prevent slipping. The results indicate that the double overhand also works to prevent tightening. This may be attributed partly to the friction in the additional throw and partly to the awkward ‘D’ shape that such knots adopt during tightening, the ideal being more circular.

The constrictor knot was the only ligature that retained tension well. The SDOS knot and the modified surgeon’s knot were intermediate, and the surgeon’s knot, strangle knot and modified miller’s knot retained very little tension. The constrictor knot’s performance was consistent with its reputation, it being commonly used without any additional locking knots to secure sacks or prevent a rope’s end fraying.

The strangle knot and modified miller’s knot are essentially identical except for the location of the crossing strand (Fig 1). Veterinary surgeons use them when tying off the uterine pedicle; both ligatures tighten easily and clamp down through surrounding fatty tissue to compress an artery. However, when the weight was removed in these trials, both ligatures markedly lost tension. In practice, these ligatures may be appreciated more for their ability to be tightened rather than for their ability to stay tight.

Two versions of the surgeon’s knot were tested: one with a single turn around the rod and the other (the modified surgeon’s knot) comprising two turns, which allowed for fairer comparison with the other knots, all of which also comprised two turns. As expected, the modified surgeon’s knot performed better than the surgeon’s knot but the constrictor knot outperformed them both.

Suture materials and friction
The constrictor preserved tension much better when tied using polydioxanone than when tied using polyglactin, suggesting that the former is better for tying ligatures.

Equipment
The modified Taylor bench provided consistent, repeatable, linear relationships between force and weight for all four suture materials. It employed a manually rotated crank and some variation in the rate was unavoidable. The effect of doubling or halving the rate was observed with no obvious change in the results. In this trial, the measurement was based on the peak values occurring at (or just prior to) slipping and therefore prior to the generation of heat in the ligature. The tests produced consistent results as evidenced by the small values for the standard errors of their means.
Conclusions

For use as a ligature, the constrictor knot outperformed the other knots. In surgery performed by one of the authors (HT) and in our trials, it clamped down smoothly and remained tight. These features commend it for use as a ligature in human and veterinary surgery. Surgeons in training should be taught the constrictor knot.

The surgeon’s knot has been a standard ligature. However, despite the double overhand component, it retained tension poorly. The version with two turns (the modified surgeon’s knot) performed better (roughly as well as the SDOS knot) and was more convenient to tie. The strangle knot and the modified miller’s knot retained little tension, and appear to be less suited for use as ligatures.

The suture materials differed in the friction within the knot portion of the ligature. Polydioxanone had the greatest ability to retain tension in a ligature and polyglactin the least.

In the veterinary practice of one of the authors (HT), it is hard to break the custom of using additional half knots. Continuing to do so probably remains a prudent safeguard even when using the constrictor knot as a ligature and we advocate their use.

The modified Taylor bench provided an accurate comparison between ligatures and suture materials, and we recommend a bench of this type for similar, future laboratory tests.

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